An analysis of the impact of negative CSR 'Forced Labour' parameter on the profitability of Supply Chain Contracts

Abstract.

This paper provides a mathematical model to analyse the impact of a negative corporate social responsibility (CSR) parameter that for ‘forced labour’, on supply chain profitability based on coordination contracts. Four types of supply chain coordination contract are developed and benchmarked against set performance indices employing sensitivity analysis and non-linear optimization techniques. *Nash* ‘static’ and *Stackelberg* ‘dynamic’ models are employed to represent the ‘gameplay’ between the ‘manufacturer’ and ‘retailer’ in a supply chain. The key inputs are average demand and ‘forced labour’ ratios, whereas key performance indicators are advertising, inventory and pricing costs.

Our results indicate that by reducing the proportion of ‘forced labour’ for both members of the supply chain, the overall profitability increases in a *Nash* static gaming context. However, the contractual relationships in a *Stackelberg* dynamic situation provide a different picture. Here, if the ‘retailer’ assumes the leadership role, cost-sharing contracts increase the profitability for both partners. However, if the ‘manufacturer’ assumes the leader, the profit-sharing contract leads to the highest overall profit. Furthermore, sensitivity analysis confirms that an ideal situation is one in which the ‘forced labour’ ratio approaches ‘zero’, where the profitability of the retailer is usually higher than that of the manufacturer. Previous researchers have used ‘survey-based’ methods to develop proportional or ‘mediating’ relationships to measure the impact of CSR on supply chain profitability. This paper addresses the associated gap by providing a game theoretic-based non-linear mathematical model to assess the direct impact of negative CSR on supply chain profitability and benchmarks the performance of different supply chain contracts.

Keywords. Corporate Social Responsibility; Supply Chain coordination; Game Theory; Nash and Stackelberg Equilibrium.

1. Introduction

Corporate social responsibility (CSR) is defined as "a social and ethical behaviour against stakeholders that enhances society's welfare and some standards have been edited for it through laws and guidelines" (ISO 26000, Working Group on Social Responsibility, 2007). Few scholars have considered CSR in the field of social responsibility and innovation in the supply chain (Seuring and Müller, 2008; Ashby et al., 2012; Ahi and Searcy, 2015; Puska et al., 2018; Fazlollahtabar 2018; Lukovac and Popovic, 2018). Corporate Social Responsibility in a supply chain (SC) context is defined as the social and ethical behaviour of SC members towards all stakeholders, which includes shareholders, end customers, employees and managers (Panda, 2014). In SC modelling, quantitative and measurable variables are necessary to measure CSR. There are various references that classify social responsibility indicators, including the Global Reporting Initiative which classifies labour practices, good and suitable work, human rights, products, and social responsibility. Several indicators have been investigated using quantitative measures of social responsibility such as vacation, staff turnover, wage level of sexes, and promotion rate (Katsikea et al., 2014; Kwon & Milgrom, 2014; Mani et al., 2014; Simoes et al., 2016; Strandberg et al., 2017). From the supply chain perspective, the collaborated network is primarily designed to improve communication amongst its members by developing long-term relationships to increase their profit margins (Govindan et al., 2012). In reality, a decision made by one member can easily have an impact on other members of the supply chain (Heydari, 2014). Many studies have indicated that a conflicting approach can increase the profitability of one member at the expense of others (Jia et al., 2013; Mahdiraji et al., 2014, 2015 and 2019); however, a cooperative decision-making approach enhances the overall profitability of all members. Coordination network models have been developed to motivate all members or players to make optimal decisions and resolve any conflicts that exist. In this regard, game theory methodology has been used to investigate the pay-off function in the instance of a conflict between two or more players (Mahdiraji et al., 2015). In non-cooperative games, whilst the bargaining power of different players is equal, the game is termed as *Nash* (Mahdiraji et al, 2014). However, when one player dominates the market or SC and is considered to be the leader, and where the other(s) obey as follower(s), it is termed *Stackelberg* (Jia et al, 2013). On the other hand, cooperative games employ coordination contracts as a recognized tool that takes into account all members' dilemmas (Xu et al., 2017). Coordination contracts such as profit sharing, revenue sharing, cost-sharing, buy-back, quantity discount, two-part tariff, etc., not only assume SC members' individual targets but also lead to overall higher performance (see, for example, Wang et al., 2013; Goering, 2012; Panda et al., 2017; Raj et al., 2018; Ma et al., 2017).

Our extant literature review indicates that in the vast majority of cases, CSR has been considered to be a qualitative factor only, and not has been considered as a quantitative decision-making variable in a mathematical treatise.

Among CSR's various key indicators, in this research forced labour has been identified as the most prominent indicator of SC members (Mahdiraji et al., 2019). The forced labour ratio, herein labelled BL_{ratio}, is defined as the registered percentage of forced labour in the SC (Mani et al., 2014). From the SC point of view, supply chains usually aim to maximize their overall profit by engaging an inappropriate target and distribute equitable shares to all parties. Hence, considering a chosen CSR indicator in a market and demand function, how the outcomes and payoff functions for different members in a chain will alternate? Moreover, how the changes in the CSR indicator affects different coordination contracts structure and model? Alongside with, which coordination contract and which player benefits more for different amounts of CSR indicator? Eventually, what are the appropriate conditions, contracts and CSR indicator values for gaining higher value for supply chain overall profit? Therefore, this research is concerned with the modelling and optimization of the profit margin of the supply chain, as consisting of a retailer and a manufacturer whilst they are engaged in a 'forced labour' negative CSR publicity situation.

In our proposed approach, the demand function has used the social responsibility measurement index. In fact, besides price and advertisement factors, demand also depends on the manufacturer's social responsibility performance. Considering a specific CSR index in the demand function, by preparing a suitable tool to analyse the effects of CSR on each member and the SC's overall profit, has, to our knowledge, never been previously considered in any related research. In particular, four coordination contracts, namely profit sharing, revenue sharing, cost sharing, and two-part tariff, are modelled, optimized and examined, considering *Nash* bargaining and *Stackelberg* leadership scenarios. Note that the authors determine optimal pricing, ordering, advertising and social responsibility policies under Nash static game conditions, where each supply chain member enjoys equal bargaining power. Further, the authors evaluate the same scenarios under Stackelberg's dynamic situation, where members enjoy asymmetric bargaining power. The researchers examine the profitability of these contracts whilst the SC is undergoing the various levels of negative CSR publicity due to the forced labour issues identified. The overall research framework is illustrated in Figure1.

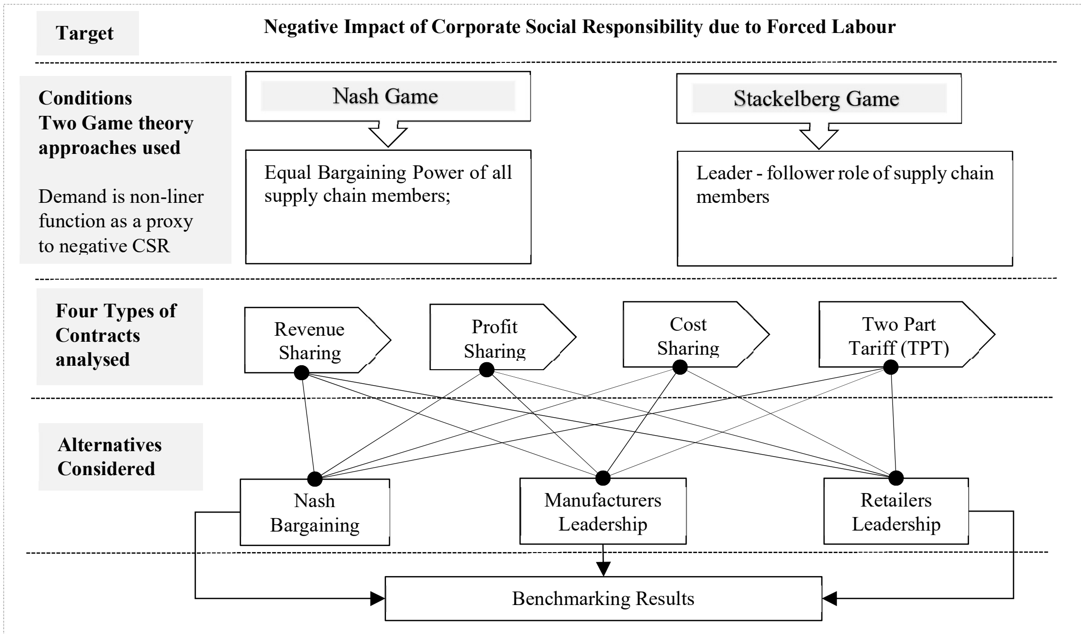


Figure 1. Research Framework

The structure of the paper is organized as follows. At first, the relevant literature in the field of CSR is presented and the different coordination contracts employed in SC are presented. Secondly, a research methodology is proposed, and the initial conditions and assumptions made are outlined. Subsequently, relevant symbols, the profit function of each player, concavity, the output response for each member, and parameters to determine the optimal solution are discussed. Finally, the model is tested using a numerical example and a sensitivity analysis of corporate social responsibility will be presented.

2. Coordination contracts in the Supply Chain: A literature review

Supply chain management is to line the associated material flow coordination and inventory policies in order to maximize its profit. The planning of important decisions in a multi-echelon chain could affect all the levels and the SC as a whole (Stadtler, Kilger, 2007). If each player (or company) creates their own inventory, pricing, and advertising policies whilst ignoring the others, the supply will not be able to meet the demand cycle. This results in extreme financial and non-financial challenges resulting in, for example, loss of profit, loss of customer loyalty, bad repute and, in extreme situations, the total loss of the business. In order to avoid this, supply chains adopt methods of coordination that require collaboration at different levels (Esmaeili *et al*., 2009; Mahdiraji *et al*., 2012 and 2015). In a slow-moving supply chain, for example, the construction industry, chemical industry, or agriculture, the 'demand pattern' is highly predictable; therefore, revenue sharing, cost sharing, profit sharing, two-part tariff, etc., contracts are suitable. On the other hand, in a dynamic environment or fast-moving goods industry, with unpredictable demand (represented by probabilistic or stochastic functions), rebate contracts or buyback contracts are more appropriate (Mahdiraji et al., 2019). There are, however, some types of coordination contract that are suitable for either situation. The researchers provide a summary of various coordination contract types that suit different demand patterns in Figure 2.

S/P (Stochastic or Probablisitc deamnd)	D (Deterministic demand) +A (All Situations)
• Profit Warranty • Subsidary Cost Sharing • Quantity Flexible • Buyback • APD (Advaced Purchase Discount) • Information Sharing	• Revenue Sharing • Wholeprice Discount • Cost Sharing • Two Part Tariff • Profit Sharing • Share Effort • Rebate

Figure 2. Classification of Coordination Contracts based upon Deterministic/Stochastic Situation

The researchers have conducted an in-depth review of the literature published since 2009 on coordination contracts in the supply chain. A summary of the literature review is provided in Table 1 under which the literature is grouped according to whether the CSR was part of the contract, levels of supply chain, the type of demand function (i.e., linear, deterministic, non-linear, stochastic), demand function variables (i.e., price, effort, quality, marketing/advertising, CSR/low carbon/green), planning horizon (i.e., single period or multi-period), and the main variables of the model (i.e., price, quality, advertising cost, share of income, order quantity, cost efficiency). The outcome of this review suggests that there are only a few examples where CSR has been addressed as demand parameters in these studies. For example, Hsueh (2014) evaluated a revenue-sharing contract model where he considered social responsibility as the demand-dependent variable to determine its impact on price/order quantity and revenue sharing. Ghosh and Shah (2015) considered a cost-sharing model of the impact of the 'green variable' as dependent on price/order quantity and measured the outcome of 'green effort' spent in an SC. Xu and Bai (2016) examined revenue sharing/two-part tariff (TPT) contracts to measure the impact of supply chain 'sustainability' level and its impact on revenue/profitability. Zhou et al. (2016) considered the impact of 'low carbon' advertising and price escalation on cost-sharing contracts. Wang, Zhao and He (2016) studied the impact of 'low-carbon' advertising on a cost-sharing contract, whilst Peng, Pang, and Cong (2018) measured the 'emission reduction' in SC with regard to the revenue sharing contract. More recently, Hong and Guo (2019) and Qian et al. (2020) examined the impact of green product and green marketing on price in cost-sharing and TPT contracts.

In our extant literature review (Table 1 in Appendix 1), the researchers have identified sixteen different kinds of contracts that researchers have proposed in a supply-chain context. The researchers summarise this in pie chart format in Figure 3. For simplicity, the researchers have converted the numeric value of contract types (i.e., out of 15) into a percentage. The authors identify that revenue sharing (29%), wholesale contract (23%), cost-sharing (8%), and buyback (5%) are the most representative types in the previous research.

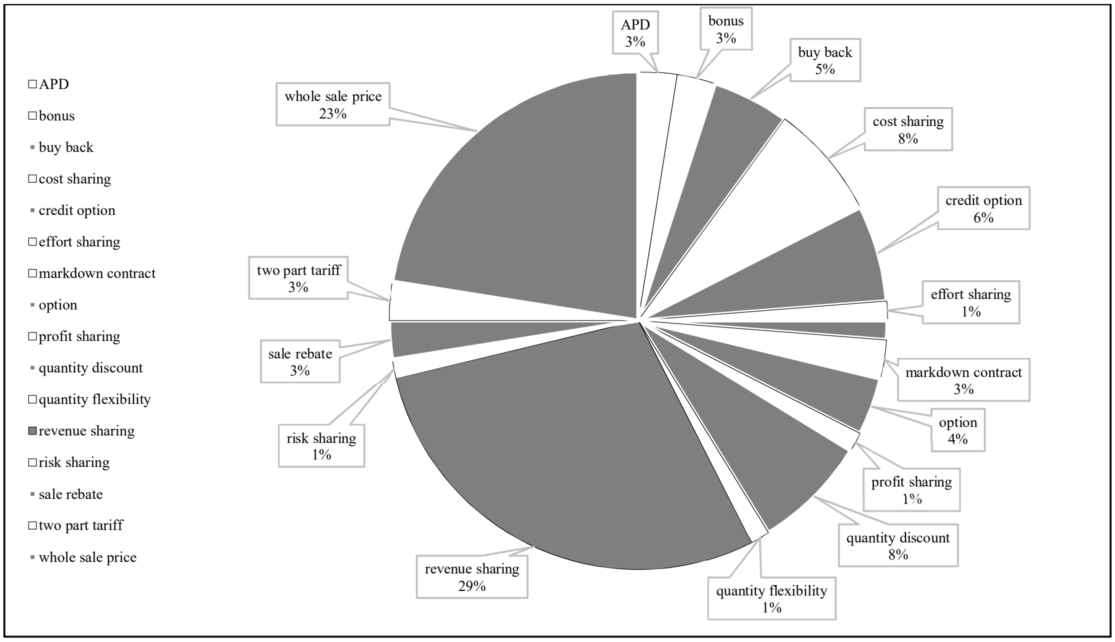


Figure 3. The contribution of different contracts of various supply chain coordination methods

As indicated earlier, the authors have selected four types of coordination contract to examine the impact of negative CSR publicity arising from forced labour situations. Note that, considering the deterministic demand function type of this research (upon Figure 2), contracts suitable for uncertain demand functions were not usable. Thus, among the possible contracts for deterministic demand function, the most prominent contracts were chosen based on figure 3; each is explained briefly in the following. The mathematical formulation of these contracts is developed in sections three and four.

[1]. ***Revenue sharing contract.*** This contract mainly applies to online businesses. In fact, this contract reduces the wholesale price and divides profit between the contractual parties according to their bargaining power (Krishnan & Winter, 2011; Sluis & Giovanni, 2016; Xie et al, 2017).

[2]. ***Profit-sharing contract.*** This provides unequal profit sharing amongst the members, usually reflecting their bargaining power. The profit-sharing contract leads to higher coordination in SC and increases overall profit (see, for example, Jaber & Osman, 2006; Cao et al., 2015).

[3]. ***Two-part tariff contract (TPT)***. The manufacturer offers a fixed price to the retailer in addition to the wholesale price. In fact, coordination will occur if the optimal price is equal to the price in two-part tariff conditions in the centralized mode (Xu et al, 2016).

[4]. ***Cost-sharing contract***. Suited to share the costs of research and development, marketing, energy storage, social responsibility, etc., amongst the members (Frisk, Goethe-Lundgren et al., 2010; Zhou, Bao et al., 2016).

In summary, our literature review illustrates previous research that has examined supply chain contracts from a variety of dimensions, including variables, production type, cooperation status, SC levels, etc. (see Table 1 in Appendix 1). However, the authors note that all these researchers considered single product types, complete information games, and sensitivity analysis for validation. By comparing our proposed approach with similar research, the novelty and contribution of our own efforts are illustrated in the last row of Appendix 1. In particular, the multiplicity of the demand function, CSR issues (in particular, use of forced labour as a proxy to negative CSR), use of a measurement index of social responsibility, gaming approaches used, and the validation and verification approach that is employed make our research distinctive. Table 2 offers a summary of the main contributions presented in this paper. Note that, Nash and Stackelberg games are performed in many management and economic areas. However, the main focus of this research is the utilization of a CSR indicator to design coordination contracts in a two-echelon supply chain and to analyse the effects of this indicator on the profitability of players and the entire SC.

Table 2. Comparative value and contribution made by this research

Aspect	Previous Researches	Proposed Research
Corporate Social Responsibility (CSR)	• The previous research considered CSR to be a qualitative issue. CSR has not been: ➢ Examined as a decision variable in a quantitative model; ➢ Considered in coordination contracts; ➢ Considered in terms of the overall profitability of a supply chain;	• CSR is considered to be a quantitative decision-making variable • A measuring index is developed for CSR as a function to measure and analyse the effect of CSR on supply chain profitability;
Demand Function	• Earlier research has considered demand function to be: ➢ Deterministic ➢ A simple regression ➢ A nonlinear function dependent on price, advertising, etc.	• The demand function is modelled as a three-dimensional nonlinear function depending on price, marketing costs and CSR measuring index; • None of the previous research has considered a CSR in-demand function.
Contracts and Game theory	• Previous research considered contracts based upon Nash or Stackelberg Game conditions.	• Four types of coordination contract are analysed including revenue sharing, cost sharing, profit sharing, and two-part tariff; • All contracts were benchmarked according to three situations including Nash, retailers' leadership and manufacturers' leadership Stackelberg conditions.

3. Proposed Model

In this section, the game-theoretic, mathematical modelling, supply chain, and coordination contract assumptions (section 3.1) will first be presented. The CSR indicator is then discussed and selected (section 3.2) for further purposes. Next, the notations for mathematical modelling are illustrated and the payoff function for two-player SC members is demonstrated (section 3.3).

3.1. Problem description and assumptions

In this research, a two-echelon supply chain including a manufacturer and a retailer dealing with a single product is considered. The final product demand function is dependent on price, advertising costs, and social responsibility measuring indices. Among the demand function variables, social responsibility (forced labour ratio) and price have an inverse relation with demand. Note that D is demand, θ is a fixed coefficient of demand function, α presents the retailer's price (P_r) elasticity, β denotes the elasticity of advertising costs (C_r) and γ measures the impact of corporate social responsibility (CSR_M) measuring index efforts, as presented in Equation (1).

$$D = \theta . P_r{}^{-\alpha} . C_r{}^{\beta} . CSR_M{}^{-\gamma} \qquad \text{Eq. (1)}$$

The retailer pays for advertising costs and the manufacturer is responsible for social responsibility costs. Based upon game theory classifications, both parties have access to complete information with a non-repetitive game and enjoy cooperative behaviour. Accordingly, the Nash bargaining game and Stackelberg Leader-Follower game have been employed to analyse the applicability of the proposed model. In addition, coordination contracts for profit sharing, revenue sharing, two-part tariff and cost sharing in static and dynamic games have been investigated. Moreover, the best response from each decision variable for each player resulted from the Nash definition (Jia et al., 2013). By considering the Nash definition, each player will stimulate competitors beliefs or best responses and, while these beliefs are correct, Nash equilibrium will occur (Mahdiraji et al., 2015).

The problem of SC coordination is modelled assuming equal bargaining power of members as well as one player having dominant power. It should be noted that, in a profit-sharing contract, bargaining with regard to the profit realized by each member is based on agreement type. However, in the revenue sharing contract, the wholesale price is lower than the unit production cost, let alone its maintenance and ordering costs. Furthermore, in the TPT contract, the wholesale price is higher than the unit production cost and in addition to the wholesale price W_m, a fixed cost of t_m is provided for the retailer. Eventually, the cost-sharing contract has been applied under sharing advertising costs.

The proposed research methodology is composed of three stages. First of all, modelling the outcomes for the retailer and manufacturer are investigated. Secondly, the best responses for each player in both Nash and Stackelberg game situations is evaluated for four coordination contract types. Thirdly, using a numerical example, a sensitivity analysis of the corporate social responsibility measuring index is conducted as illustrated in Figure 4.

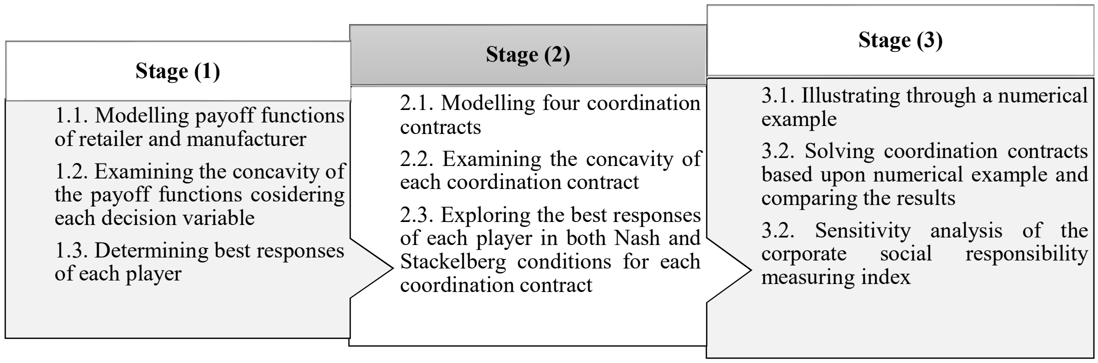


Figure 4. Research stages

3.2. Corporate Social Responsibility Measuring Indices

There are various references for classifying social responsibility indicators. One of the most common includes the Global Slavery Index (GSI) that relates directly to the use of forced labour. However, through the literature review, the authors have identified a number of indices that previous researchers have identified as means by which to quantify social responsibility, as summarized in Table 3.

Table3. Measures s of social responsibility (Source: Authors)

Research	Quantitative indicators examined
(Azapagic & Perdan, 2000)	Distribution of income Job satisfaction
(ICheme, 2002)	Staff turnover Promotion rate
(Szekely & Knirsch, 2005)	Crashes Education Gender ratio Disabled employees The collective bargaining agreements
(Kruse et al., 2009)	Working hours
(de Bloom, et al., 2009)	Vacation
(Cascio, 2010)	Dismissal of employees
(Lim, Chan, & Dallimore, 2010)	Full-time and part-time employees Years of service
(GRI, 2011)	Employee safety training
(DPE, 2011)	Collective bargaining agreements
(Erol, Sencer, & Sari, 2011)	Discrimination Staff complaints
(OECD, 2012)	Job dissatisfaction
(Katsikea et al., 2014)	Staff turnover
(Kwon & Milgrom, 2014)	Promotion rate (promotion)
(Mani et al., 2014)	Wage levels between the sexes
(Simoes et al., 2016)	Staff turnover
(Strandberg et al., 2017)	Vacation
(ILO, 2017; Mahdiraji et al., 2019)	Forced labour

The above-mentioned indicators are considered in different research efforts. Note that there are several references to classify CSR indicators. Some of these indicators have resulted from the combination of CSR with other sustainability pillars. In this regard, environmental performance indicators are used to modify CSR metrics in the literature (e.g., Searcy et al., 2016; Prasad et al., 2019). There are no preferences among these indicators; however, those emanating from the GRI global report and modified for a specific situation are more respectable. Moreover, there is an annual report regarding Corporate Responsibility Indicators from the united nations that are also popular.

Ciliberti et al. (2011) analysed CSR codes and principal-agent problems in supply chains. Using four case studies, they evaluated the impact of SA8000. SA8000 is a voluntary accountability standard developed by Social Accountability International (SAI) in 1997 that is mainly based on the Universal Declaration of Human Rights and International Labour Organisation (ILO) conventions (Leipziger, 2001; Liu et al., 2019). The findings of this research suggest that implementing the SA8000 code of practice reduces the information asymmetry and thereby enhances transparency amongst the members of a supply chain. Moreover, this minimizes opportunistic behaviour amongst the supply chain network as well as reducing moral hazards. However, this does not necessarily convince customers to add a premium to the costs of their products to mitigate against the cost of implementing the code.

Accident indicators, number of reported accidents per year, health coverage, number of employees with social security, health insurance, ratio of male to female employees, level of payment between genders, income distribution among employees and forced labour factors are all key indicators for measuring sustainability and social responsibility (Mahdiraji et al., 2019). Among them, forced labour is defined as "All work or service that is exacted from any person under the menace of any penalty and for which the said person has not offered himself voluntarily" (ILO, 2017, online). This term is classified in Figure 5 by the International Labour Organization (ILO).

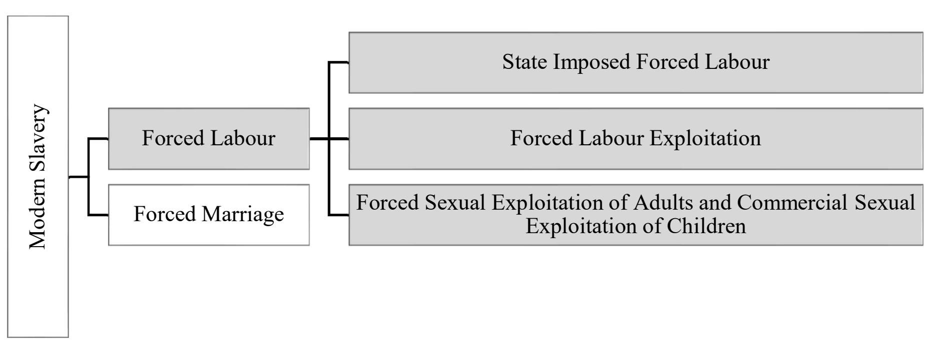


Figure 5. Modern Slavery classification, including forced labour (Source: ILO, 2017)

In our research, the forced labour section, including all three subsidiaries, has been considered in our proposed procedure. The status of the worldwide forced labour situation is demonstrated in Figure 6 for the reader's further information.

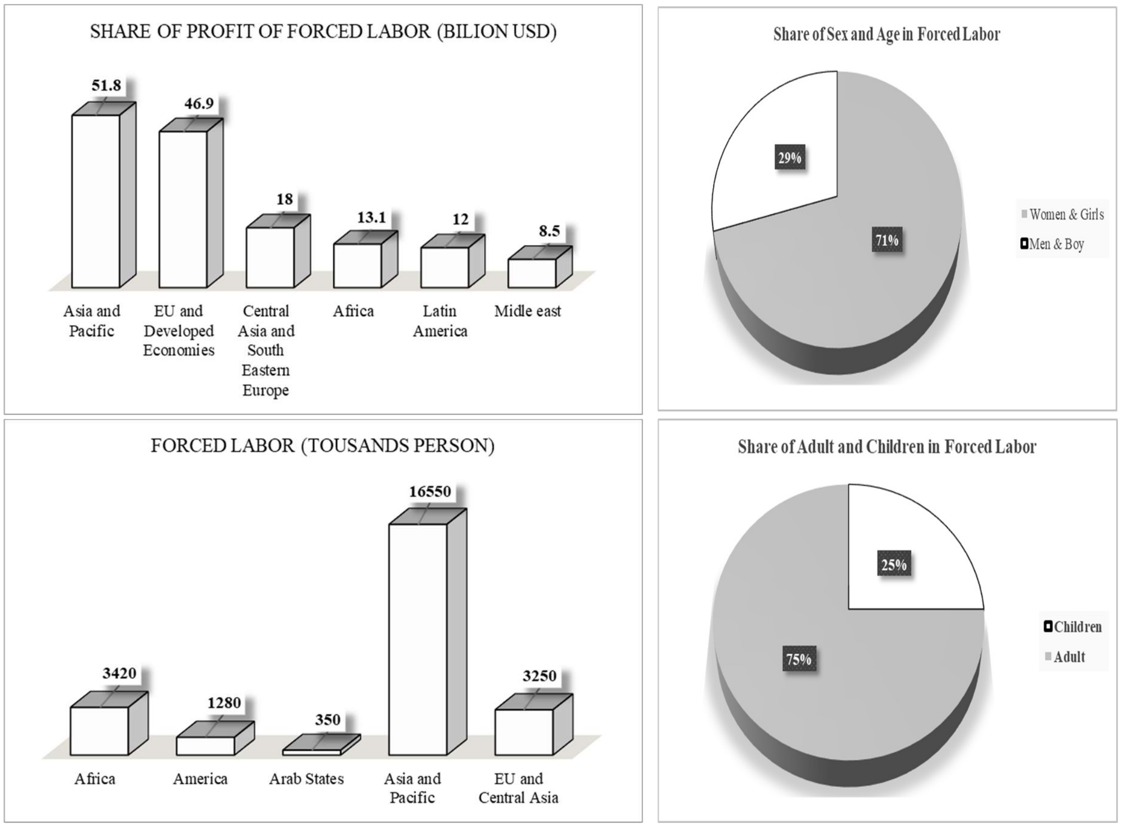


Figure 6. Forced Labour Information (Source: ILO, 2016; ILO, 2017)

As indicated earlier, the authors use forced labour as a proxy for negative CSR that ultimately leads to bad publicity and loss of reputation and business in a supply chain. The main assumptions are that a larger percentage use of forced labour in a supply network would lead to bad publicity and a decline in the demand for the product or service. Therefore, the network would need to spend more effort and money on advertising and marketing to mitigate this negative impact. This leads to an increment in the total cost of products or services in the network. As mentioned earlier, the authors introduce forced labour BL_{ratio} as the quantitative measure representing the percentage of registered forced labour amongst SC members (Mahdiraji et al., 2019). Next, this index is included in the SC models through the demand function, as based on Table 4.

Table 4. Selected Index Description (Source: Mahdiraji et al., 2019)

ID	BL_{ratio}
Descriptions	Percent forced labour working in the supply chain
Formula	$BL_{ratio} = \frac{BL}{N_{tot}} \times 100$ Eq. (2)
Unit of measure	Percentage

Measuring range	Minimum 0 and a maximum of 100% ($0 \leq BL_{ratio} \leq 1$)
Process	Less, better
Scale	Whole supply chain
Scheduling	Periodically based on demand
Audiences	Management; Customer; Public audits; Government
Additional explanation	This indicator should be part of external auditing

In equation (2), BL is the amount of registered (forced) labour in an SC network and N_{tot} denotes the total number of employees. This indicator has been derived from the ratio of forced labour to the total number of employees at the desired level, which therefore has an inverse relationship to demand function (Mahdiraji et al., 2019). Considering equation (1) and (2), the final demand function is presented as follows.

$$\left.\begin{array}{l} D = \theta . P_R{}^{-\alpha} . C_R{}^{\beta} . CSR_M{}^{-\gamma} \\ CSR_M = BL_{ratio_M} = \left(\frac{BL_M}{L_{tot_M}}\right) \end{array}\right\} \rightarrow D = \theta . P_R{}^{-\alpha} . C_R{}^{\beta} . BL_{ratio_M}{}^{-\gamma} \qquad \text{Eq. (3)}$$

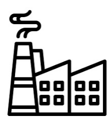
Where D is demand, α the price elasticity, β the elasticity of advertising, and γ measures the elasticity of social responsibility measuring index efforts.

3.3. Mathematical model

Table 5 provides a list of variables and symbols used in our model. Here, the retailer is R and manufacturer is M. In addition, F stands for mathematical function, P for parameters and V for decision variables. Note that the MATLAB software was used for determining and solving optimal values in the subsequent sections.

Table 5. Symbols used for modelling retailer and manufacturer implications

Player	Icon	Symbol	Type	Description
Retailer		G_R	F	profit margin
		TR_R	F	total revenue
		TC_R	F	total cost
		π_R	F	payoff
		THC_R	F	total holding cost
		TOC_R	F	total ordering cost
		TMC_R	F	total marketing cost
		C_{O_R}	P	ordering cost
		C_{h_R}	P	holding cost per unit
		P_R	P	selling price
		C_R	V	marketing costs per unit
		Q_R	V	ordering quantity
		Z	V	retail price ratio in a contract

Player	Icon	Symbol	Type	Description
Manufacturer		G_M	F	profit margin
		TR_M	F	total revenue
		TC_M	F	total cost
		π_M	F	payoff
		THC_M	F	total holding cost
		$TOSC_M$	F	setup and ordering cost
		TBC_M	F	total purchase/buy cost
		TSC_M	F	total shortages/ stock out cost
		TPC_M	F	total production cost
		TO_M	F	total ordering cost
		TS_M	F	total setup cost
		TRC_M	F	manufacturer's total related costs
		φ_M	F	demand ratio on manufacturers capacity
		CSR_M	F	social responsibility measurement index
		L_{tot_M}	P	total number of employees
		BL_M	P	number of registered labour workforce
		PC_M	P	production capacity
		C_{S_M}	P	setup costs
		u_M	P	cost function per unit product
		δ_M	P	coefficient of scale advantage
		C_{h_M}	P	holding cost per unit
		C_{B_M}	P	shortages cost per unit
		C_{P_M}	P	raw material purchase costs per unit
		C_{L_M}	P	production costs per unit
		η_M	P	social responsibility criteria for each product
		C_{O_M}	P	ordering cost
		P_M	V	wholesale price
		Q_M	V	production quantity
		B_M	V	shortages
Supply Chain		D	F	demand function
		BL_{ratio_M}	F	labour income index for measuring social responsibility
		E	P	BL ratio coefficient
		$\theta, \alpha, \beta, \gamma$	P	demand coefficient, price elasticity, advertising, social responsibility
		Θ	P	price ratio coefficient in a contract
		ב	V	profit-sharing contract coefficient
		A	V	bargaining power

Player	Icon	Symbol	Type	Description
		t_m	V	two-part tariff contract coefficient
		P	V	revenue sharing contract coefficient
		w_m	V	wholesale price in a contract
		Ω	V	cost-sharing contract coefficient

The retailer's income is derived from multiplying the profit margin against the product demand. The profit margin of the retailer, Eq. (4), results from the difference between the wholesale purchase price and the retail price to the final customer.

$$\left.\begin{array}{r} TR_R = G_R \times D \\ G_R = P_R - P_M \end{array}\right\} \rightarrow TR_R = [P_R - P_M] \times \theta . {P_R}^{-\alpha} . {C_R}^{\beta} . {BL_{ratio_M}}^{-\gamma} \qquad \text{Eq. (4)}$$

The retailers total cost (TC_R) includes holding (THC_R), ordering (TOC_R) and advertising costs (TMC_R), as given in Eq. (5). Note that the economic order quantity (EOQ) model has been considered for the retailer (Mahdiraji et al., 2014, 2015).

$$\left.\begin{array}{r} TC_R = TMC_R + TOC_R + THC_R \\ TMC_R = D \times C_R \\ TOC_R = C_{O_R} \times \dfrac{D}{Q_R} \\ THC_R = \dfrac{1}{2} \times \ Q_R \ \times C_{h_R} \times P_M \end{array}\right\} \rightarrow TC_R = \left(\theta . {P_R}^{-\alpha} . {C_R}^{\beta} . {BL_{ratio_M}}^{-\gamma} \times \left[C_R + \left(C_{O_R} . {Q_R}^{-1}\right)\right]\right) + (\frac{1}{2} \times \ Q_R \ \times C_{h_R} \times P_M) \qquad \text{Eq. (5)}$$

The retailers supply the product from the manufacturer and are responsible for selling them to the final customer. (Lee et al., 1996; Esmaeili et al., 2009; Ma et al., 2013; Jia et al., 2013; Mahdiraji et al., 2015, 2019). The retailers costs include the costs of ordering, holding and advertising spent on each product. To illustrate the retailer's profit function, π_R has been derived from the difference between income and retailer costs. The retailer's restrictions include a positive profit margin and a demand greater than zero while requiring less than the manufacturer's production capacity. Accordingly, the retailer payoff function is designed as follows.

$$\pi_R = \left(\theta . {P_R}^{-\alpha} . {C_R}^{\beta} . {BL_{ratio_M}}^{-\gamma} \times \left[[P_R - P_M - C_R] - C_{O_R} . {Q_R}^{-1}\right]\right) - (\tfrac{1}{2} \times \ Q_R \times C_{h_R} \times P_M) \qquad \text{Eq. (6)}$$

The manufacturer's profit is derived from the wholesale income minus costs of purchasing raw materials, shortage costs (TBC_M), setup costs, production costs (TPC_M), holding costs and cost of advertisement to mitigate against the impact of forced labour (Wang & Tang, 2009; Oganezov, 2006; Chakraborty et al., 2010; Chang, 2008; Pentico et al., 2009; Jia et al., 2013; Mahdiraji et al., 2014, 2015). Shortages are effectively compensated for by delayed orders. The manufacturer has a warehouse for storing the final product. The total income of the manufacturer (TR_M) consists of multiplying the manufacturer's profit margin by the demand. The profit margin for the manufacturer has been derived from the difference between the wholesale price and production costs and cost of implementing social responsibility, according to Eq. (7).

$$\left.\begin{array}{c} TR_M = G_M \times D \\ G_M = P_M - C_{P_M} - C_{L_M} - \eta_M BL_{ratio_M} \\ TBC_M = C_{P_M} \times D \end{array}\right\} \rightarrow TR_M = [P_M - C_{P_M} - \eta_M BL_{ratio_M}] \times \theta . P_R{}^{-\alpha} . C_R{}^{\beta} . BL_{ratio_M}{}^{-\gamma} \qquad \text{Eq. (7)}$$

Total setup costs for the manufacturer (TS_M) and the cost of ordering raw materials from the suppliers (TO_M) are presented in Eq. (8) based on the economic production quantity (EPQ) model with shortages.

$$\left.\begin{array}{c} TOSC_M = TO_M + TS_M \\ TS_M = C_{S_M} \times \frac{D}{Q_M} \\ TO_M = C_{O_M} \times \frac{D}{Q_M} \end{array}\right\} \rightarrow TOSC_M = [C_{S_M} + C_{O_M}] \times \frac{\theta . P_R{}^{-\alpha} . C_R{}^{\beta} . BL_{ratio_M}{}^{-\gamma}}{Q_M} \qquad \text{Eq. (8)}$$

The total cost of production (TPC_M) includes the cost of production per unit (C_{L_M}) multiplied by the demand. Note that the variable cost of production per unit is considered to be a function of product demand ($u_M \times D^{-\delta}$). As demand increases, due to scale advantage the variable cost of production will decrease and is represented as a coefficient of the scale δ (Mahdiraji et al., 2015), as per Eq. (9).

$$\left.\begin{array}{c} TPC_M = C_{L_M} \times D \\ C_{L_M} = u_M \times D^{-\delta} \\ if \quad 0 < \delta_M < 1, u_M > 0 \end{array}\right\} \rightarrow TPC_m = u_M \times D^{1-\delta} = u_M \times \theta^{1-\delta_M} . P_{R_M}{}^{-\alpha.(1-\delta_M)} . C_{R_M}{}^{\beta.(1-\delta_M)} . BL_{ratio_M}{}^{-\gamma.(1-\delta_M)} \qquad \text{Eq. (9)}$$

The total inventory-related costs for the manufacturer (TRC_M) include the final product handling cost (THC_M) and shortage costs (TSC_M) (Wang & Tang, 2009; Oganezov, 2006; Chakraborty et al., 2010; Chang, 2008; Pentico et al., 2009; Razavi Hajiagha et al., 2015), as represented in equation (10). It should be noted that the EPQ model with shortages has been considered for the manufacturer.

$$\left.\begin{array}{c} TRC_M = THC_M + TSC_M \\ THC_M = C_{h_M} \times \frac{(\varphi_M \times Q_M - B_M)^2}{2 \times \varphi_M \times Q_M} \\ TSC_M = \frac{C_{B_M} \times B_M{}^2}{2 \times \varphi_M \times Q_M} \\ \varphi_M = 1 - \frac{D}{PC_M} \end{array}\right\} \rightarrow TRC_M$$
$$= \left(C_{h_M} \times \frac{((1 - \frac{\theta . P_R{}^{-\alpha} . C_R{}^{\beta} . BL_{ratio_M}{}^{-\gamma}}{PC_M}) \times Q_M - B_M)^2}{2 \times (1 - \frac{\theta . P_R{}^{-\alpha} . C_R{}^{\beta} . BL_{ratio_M}{}^{-\gamma}}{PC_M}) \times Q_M} \right) + \left(\frac{C_{B_M} \times B_M{}^2}{2 \times (1 - \frac{\theta . P_R{}^{-\alpha} . C_R{}^{\beta} . BL_{ratio_M}{}^{-\gamma}}{PC_M}) \times Q_M} \right) \qquad \text{Eq. (10)}$$

The total profit earned by the manufacturer (π_M) is the difference between total revenue and total costs, as follows.

$$\pi_M = \left([P_M - C_{P_M} - (u_M \times D^{-\delta_M}) - \eta_M BL_{ratio_M}] \times \theta . P_R{}^{-\alpha} . C_R{}^{\beta} . BL_{ratio_M}{}^{-\gamma} \right) - \left(\left(C_{h_M} \times \frac{\left(\left(1 - \frac{\theta . P_R{}^{-\alpha} . C_R{}^{\beta} . BL_{ratio_M}{}^{-\gamma}}{PC_M}\right) \times Q_M - B_M \right)^2}{2 \times \left(1 - \frac{\theta . P_R{}^{-\alpha} . C_R{}^{\beta} . BL_{ratio_M}{}^{-\gamma}}{PC_M}\right) \times Q_M} \right) + \left(\frac{C_{B_M} \times B_M{}^2}{2 \times \left(1 - \frac{\theta . P_R{}^{-\alpha} . C_R{}^{\beta} . BL_{ratio_M}{}^{-\gamma}}{PC_M}\right) \times Q_M} \right) \right) - \left([C_{S_M} + C_{O_M}] \times \frac{\theta . P_R{}^{-\alpha} . C_R{}^{\beta} . BL_{ratio_M}{}^{-\gamma}}{Q_M} \right) \qquad \text{Eq. (11)}$$

4. Coordination Modelling

In this section, the authors first present the general form of each coordination contract. Afterward, the modelling process for each contract including profit sharing (section 4.1), revenue sharing (section 4.2), two-part tariff (section 4.3) and cost-sharing contract (section 4.4) are demonstrated.

In a supply chain network, it is clear that not all of the members will enjoy equal power relations. In an ideal situation, there is usually a supply chain 'champion' who comes forward to coordinate activities to streamline the material flows and reduce the information asymmetry amongst its members and ensure transparency in accounting practices (Hajiagha et al., 2015a, 2015b). However, our recent literature review clearly indicates that supply chain relationships are still far from a partnership amongst equals. The culture of gameplay engendered through information hoarding and passing on costs to the weaker party is still rampant in SCs, which could lead to serious financial concerns in terms of ensuring the sustainability of the business. Who pays for the advertising and marketing cost to mitigate against the impacts of forced labour, and who bears any other losses due to loss of demand is a major conflict.

Coordination contracts in SC offer a way to illustrate how each member is affected by different financial relationships. The authors portray the gameplay nature of different members in an SC using the Nash and Stackelberg models. As mentioned earlier, the Nash model considers all members of SC equal in terms of decision making. However, the Stackelberg model presents a scenario whereby the SC has a leader-follower nature and there is information asymmetry and power imbalance that leads to a shift of costs onto the follower. In order to further investigate the Nash and Stackelberg models, the authors adopted the following process:

[1]. The best responses of the retailer are obtained from its payoff function;

[2]. The retailer's best responses are used in the manufacturer payoff function to derive the profit function;

[3]. The manufacturer's best responses are obtained;

[4]. For the Nash condition, the manufacturer's bargaining power, μ, and the retailers, $(1-\mu)$, are considered; accordingly, the Nash bargaining model, as based upon equation (12), is applied (Zhang, 2012).

$$\max\,(\pi_m^{X*})^{\mu}.\,(\pi_R^{X*})^{1-\mu} \qquad \text{Eq. (12)}$$

[5]. To find the equilibrium, the first derivation of the above function is utilized in equation (13). Note that X is the decision variable of each coordination contract.

$$\mu.\pi_R^{X^*}.\frac{\partial \pi_M^{X^*}}{\partial X}+(1-\mu).\pi_M^{X^*}.\frac{\partial \pi_R^{X^*}}{\partial X}=0 \qquad \text{Eq. (13)}$$

[6]. Finally, the best solutions found in steps 2 to 5 are examined in detail to evaluate the Nash and Stackelberg game situations. These steps are further employed for each coordinating contract, as described in the following subsections.

4.1. Profit-Sharing Contract

An additional parameter $\beth$ (profit sharing coefficient) is added to reflect the contractual relationship between the retailer and manufacturer as presented in equations (14) and (15), respectively.

$$\pi_R = \beth.\left(\left(\theta.{P_R}^{-\alpha}.{C_R}^{\beta}.{BL_{ratio_M}}^{-\gamma} \times \left[[P_R - P_M - C_R] - C_{O_R}.{Q_R}^{-1}\right]\right) + \left(-\tfrac{1}{2} \times Q_R \times C_{h_R} \times P_M\right)\right) \qquad \text{Eq. (14)}$$

$$\pi_M = (1-\beth).\left(\left(\left[P_M - C_{P_M} - \left(u_M \times D^{-\delta_M}\right) - \eta_M BL_{ratio_M}\right] \times \theta.{P_R}^{-\alpha}.{C_R}^{\beta}.{BL_{ratio_M}}^{-\gamma}\right) - \left(\left(\left(C_{h_M} \times \frac{\left(\left(1-\frac{\theta.{P_R}^{-\alpha}.{C_R}^{\beta}.{BL_{ratio_M}}^{-\gamma}}{PC_M}\right)\times Q_M - B_M\right)^2}{2\times\left(1-\frac{\theta.{P_R}^{-\alpha}.{C_R}^{\beta}.{BL_{ratio_M}}^{-\gamma}}{PC_M}\right)\times Q_M}\right) + \left(\frac{C_{B_M}\times {B_M}^2}{2\times\left(1-\frac{\theta.{P_R}^{-\alpha}.{C_R}^{\beta}.{BL_{ratio_M}}^{-\gamma}}{PC_M}\right)\times Q_M}\right)\right)\right) - \left(\left[C_{S_M} + C_{O_M}\right] \times \frac{\theta.{P_R}^{-\alpha}.{C_R}^{\beta}.{BL_{ratio_M}}^{-\gamma}}{Q_M}\right)\right) \qquad \text{Eq. (15)}$$

In fact, $\beth$ $(0 \leq \beth \leq 1)$ is a coefficient that effectively divides the profit derived from the agreement between two players. This coefficient reflects the fact that the retailer's profit increases proportionally to the manufacturer's loss of profit. By using the Hessian matrix, the authors concluded that the profit function is concave to all variables. By obtaining the first derivation from the retailer and manufacture functions and solving the associated set of equations, the authors obtained an optimal response for each player as illustrated in equations 16 to 22 and presented as follows.

$$\boldsymbol{{Q_R}^{*} = \sqrt{2}.\sqrt{\frac{C_{O_R}.D}{C_{h_R}.P_M}}} \qquad \text{Eq. (16)}$$

$$\boldsymbol{{P_R}^{*} = \frac{\alpha.C_{O_R}+Q_R.C_R.\alpha+\alpha.P_m.Q_R}{Q_R\times(\alpha-1)}} \qquad \text{Eq. (17)}$$

$$\boldsymbol{{C_R}^{*} = -\frac{\beta.C_{O_R}-P_R.Q_R.\beta+P_M.Q_R.\beta}{Q_R.(1+\beta)}\ IF\ \beta > 1} \qquad \text{Eq. (18)}$$

$$\boldsymbol{{Q_M}^{*} = \frac{\sqrt{2}.\sqrt{\frac{C_{h_m}.\left(\theta.{P_R}^{-\alpha}.{C_R}^{\beta}.{BL_{ratio_M}}^{-\gamma}\right).\left(1-\frac{\left(\theta.{P_R}^{-\alpha}.{C_R}^{\beta}.{BL_{ratio_M}}^{-\gamma}\right)}{PC_M}\right).\left(C_{B_M}+C_{h_M}\right).\left(C_{S_M}+C_{O_M}\right)}{C_{B_m}}}}{C_{h_m}.\left(1-\frac{\left(\theta.{P_R}^{-\alpha}.{C_R}^{\beta}.{BL_{ratio_M}}^{-\gamma}\right)}{PC_M}\right)}} \qquad \text{Eq. (19)}$$

$$\boldsymbol{{B_M}^{*} = \sqrt{2}.\sqrt{\frac{C_{h_M}.C_{B_M}.\left(\theta.{P_R}^{-\alpha}.{C_R}^{\beta}.{BL_{ratio_M}}^{-\gamma}\right).\left(1-\frac{\left(\theta.{P_R}^{-\alpha}.{C_R}^{\beta}.{BL_{ratio_M}}^{-\gamma}\right)}{PC_M}\right).\left(C_{B_M}+C_{h_M}\right).\left(C_{S_M}+C_{O_M}\right)}{{C_{B_M}}^2+C_{B_M}.C_{h_m}}}} \qquad \text{Eq. (20)}$$

$$\boldsymbol{P_M}^* =$$

$$\vartheta.\left(\frac{\sqrt{2}.C_{B_M}{}^2+C_{B_M}.C_{h_M}(\frac{D.\left[C_{S_M}+C_{O_M}\right]}{Q_M}+\left(C_{h_M}.\frac{\left(-\left(1-\frac{D}{PC_M}\right).Q_M+B_M\right)^2}{2.\left(1-\frac{(D)}{PC_M}\right).Q_M}\right)+\left(\frac{C_{B_M}.B_M{}^2}{2.\left(1-\frac{(D)}{PC_m}\right).Q_M}\right)+\frac{\sqrt{2}.\left(\eta_M BL_{ratio_M}+C_R+C_{P_M}+\left(u.D^{-\delta}\right)\right).\sqrt{C_{h_M}.C_{B_M}.(D).\left(1-\frac{(D)}{PC_M}\right).\left(C_{B_M}+C_{h_M}\right).\left(C_{S_M}+C_{O_M}\right)}}{C_{B_m}{}^2+C_{B_m}.C_{h_M}}}{2.\sqrt{C_{h_M}.C_{B_M}.(D).\left(1-\frac{(D)}{PC_M}\right).\left(C_{B_M}+C_{h_M}\right).\left(C_{S_M}+C_{O_M}\right)}}\right) \boldsymbol{IF}\ \vartheta > \mathbf{1} \qquad \text{Eq. (21)}$$

$$\boldsymbol{BL_{ratio_M}}^* =$$

$$\frac{\varepsilon}{\eta_M}.\left(-\frac{\sqrt{2}.C_{B_M}{}^2+C_{B_M}.C_{h_M}(\frac{D.\left[C_{S_M}+C_{O_M}\right]}{Q_M}+\left(C_{h_m}.\frac{\left(-\left(1-\frac{D}{PC_M}\right).Q_M+B_M\right)^2}{2.\left(1-\frac{(D)}{PC_M}\right).Q_M}\right)+\left(\frac{C_{B_M}.B_M{}^2}{2.\left(1-\frac{(D)}{PC_M}\right).Q_M}\right)+\frac{\sqrt{2}.\left(C_R-P_M+C_{P_M}+\left(u.D^{-\delta}\right)\right).\sqrt{C_{h_M}.C_{B_M}.(D).\left(1-\frac{(D)}{PC_M}\right).\left(C_{B_M}+C_{h_M}\right).\left(C_{S_M}+C_{O_M}\right)}}{C_{B_M}{}^2+C_{B_M}.C_{h_M}}}{2.\sqrt{C_{h_M}.C_{B_M}.(D).\left(1-\frac{(D)}{PC_M}\right).\left(C_{B_M}+C_{h_M}\right).\left(C_{S_M}+C_{O_M}\right)}}\right) \boldsymbol{IF}\ \varepsilon > \mathbf{1} \qquad \text{Eq. (22)}$$

Considering the *Nash game* condition, Eq. (23) is used to compute (α) and $(1-\alpha)$:

$$\max\,(\pi_M^{\beth*})^{\mu}.\,(\pi_R^{\beth*})^{1-\mu} \qquad \text{Eq. (23)}$$

In order to find the equilibrium factor, Eqs. (24) to (26) are used:

$$\mu.\pi_R^{\beth^*}.\frac{\partial\pi_M^{\beth^*}}{\partial\beth}+(1-\mu).\pi_M^{\beth^*}.\frac{\partial\pi_R^{\beth^*}}{\partial\beth}=0 \qquad \text{Eq. (24)}$$

$$\beth^* = SOLVE\left(\mu.\pi_R^{\beth^*}.\frac{\partial\pi_M^{\beth^*}}{\partial\beth}+(1-\mu).\pi_M^{\beth^*}.\frac{\partial\pi_R^{\beth^*}}{\partial\beth}=0,\beth\right) \qquad \text{Eq. (25)}$$

$$\mu^* = SOLVE\left(\mu.\pi_R^{\beth^*}.\frac{\partial\pi_M^{\beth^*}}{\partial\beth}+(1-\mu).\pi_M^{\beth^*}.\frac{\partial\pi_R^{\beth^*}}{\partial\beth}=0,\mu\right) \qquad \text{Eq. (26)}$$

All of the above cases have been coded and solved using the MATLAB software. In the Nash model, the best responses functions $Q_R{}^*$, $P_R{}^*$, $C_R{}^*$, $Q_M{}^*$, $B_M{}^*$, $P_M{}^*$, $BL_{ratio_M}{}^*$, $\beth^*$,μ^* and fundamental constraints of Eqs. (27) to (33) are solved simultaneously for optimal solutions. Eqs. (27), (28) and (33) present the scale of the coefficients, and (29), (30) and (31) denote that the demand is non-negative and less than production capacity for the retailer, whilst Eq. (32) indicates that the retailer's final price is higher than wholesale price.

$$0 \le \mu^* \le 1 \qquad \text{Eq. (27)}$$
$$0 \le BL_{ratio_M}{}^* \le 1 \qquad \text{Eq. (28)}$$
$$D = \theta.P_R{}^{-\alpha}.C_R{}^{\beta}.BL_{ratio_M}{}^{-\gamma} \qquad \text{Eq. (29)}$$
$$D \le PC_M \qquad \text{Eq. (30)}$$
$$D \ge 0 \qquad \text{Eq. (31)}$$
$$P_R - P_M > 0 \qquad \text{Eq. (32)}$$
$$0 \le \beth^* \le 1 \qquad \text{Eq. (33)}$$

To model the retailer as the leader in the *Stackelberg game,* the manufacturer is assumed to be the follower. In this model, maximizing the retailer's profit by incorporating the best response functions from the manufacturer is considered. Therefore, the objective function is to maximize the profit of the retailer, whilst the limits to this function are the manufacture's rationality and their best responses. On the other hand, the manufacturer could be considered to be the leader, thus maximizing the manufacturer's profit by considering the best responses to the retailer is of concern. Therefore, the objective function is to maximize the manufacturer's overall profit, as limited by the retailer's rationality and his best responses as model constraints. Considering the above conditions, the retailer leadership and manufacture leadership models can be described as per Eqs. (34) and (35), respectively.

$MAX\ \pi_R$ Eq. (34)

s.t:

Eq. (19, 20, 21, 22, 25, 26, 27-33)

ב*, μ^*

$MAX\ \pi_M$ Eq. (35)

s.t:

Eq. (16, 17, 18, 25, 26, 27-33)

ב* ,μ^*

4.2. Revenue sharing contract

A revenue sharing contract encourages the retailer to increase their inventory level, where the manufacturer is obliged to meet orders at a lower price than the usual wholesale price and, in return, the retailer pays them a share of the final sale price of the goods. Here, the manufacturer, by providing goods at low prices, encourages the retailer to store more goods in their warehouse. Hence, for unsold products, only a part of excess inventory risk will be assumed by the retailer. Suppose that a retailer buys their product from a manufacturer at wholesale price (w) and sells it to the final consumer at price (P_R). The size of the retailer's order is determined according to the cost function and market demand by an amount Q_R. In the revenue-sharing contract, the wholesale price is reduced from (w) to (w_m), and a $(1-\rho)$ share of the total income obtained by the retailer is paid to the manufacturer. Therefore, in Eq. (36) the wholesale price is less than the unit production cost despite the holding and ordering costs.

$$w_m < \left(\left(\left[C_{P_M} + \left(u_M \times D^{-\delta_M}\right) + \eta_M BL_{ratio_M}\right]\right) - \left(\left(C_{h_M} \times \frac{\left(\left(1-\frac{\theta.P_R{}^{-\alpha}.C_R{}^{\beta}.BL_{ratio_M}{}^{-\gamma}}{PC_M}\right).Q_M - B_M\right)^2}{2.\left(1-\frac{\theta.P_R{}^{-\alpha}.C_R{}^{\beta}.BL_{ratio_M}{}^{-\gamma}}{PC_M}\right).Q_M.D} \right) + \left(\frac{C_{B_M} \times B_M{}^2}{2.\left(1-\frac{\theta.P_R{}^{-\alpha}.C_R{}^{\beta}.BL_{ratio_M}{}^{-\gamma}}{PC_M}\right).Q_M.D} \right) \right) - \left(\left[C_{S_M} + C_{O_M}\right].\frac{1}{Q_M}\right) \right) \quad \text{Eq. (36)}$$

Note that $0 < \rho < 1$; thus, in this condition, the retailer and manufacturer's profit functions will be as depicted in Eqs. (37) and (38), respectively.

$$\pi_R = \left(\theta.P_R{}^{-\alpha}.C_R{}^{\beta}.BL_{ratio_M}{}^{-\gamma} \times \left[\left[P_R - w_m - C_R\right] - C_{O_R}.Q_R{}^{-1}\right]\right) + \left(-\frac{1}{2} \times Q_R \times C_{h_R} \times P_M\right) - \rho.P_R.Q_R \quad \text{Eq. (37)}$$

$$\pi_M = \left(\left[w_m - C_{P_M} - \left(u_M \times D^{-\delta_M}\right) - \eta_M BL_{ratio_M}\right] \times \theta . P_R{}^{-\alpha} . C_R{}^{\beta} . BL_{ratio_M}{}^{-\gamma}\right) - \left(\left(\left(C_{h_M} \times \frac{\left(\left(1-\frac{\theta . P_R{}^{-\alpha} . C_R{}^{\beta} . BL_{ratio_M}{}^{-\gamma}}{PC_M}\right)\times Q_M - B_M\right)^2}{2\times\left(1-\frac{\theta . P_R{}^{-\alpha} . C_R{}^{\beta} . BL_{ratio_M}{}^{-\gamma}}{PC_M}\right)\times Q_M}\right) + \left(\frac{C_{B_M}\times B_M{}^2}{2\times\left(1-\frac{\theta . P_R{}^{-\alpha} . C_R{}^{\beta} . BL_{ratio_M}{}^{-\gamma}}{PC_M}\right)\times Q_M}\right)\right)\right) - \left(\left[C_{S_M} + C_{O_M}\right] \times \frac{\theta . P_R{}^{-\alpha} . C_R{}^{\beta} . BL_{ratio_M}{}^{-\gamma}}{Q_M}\right) + \rho . P_R . Q_R \qquad \text{Eq. (38)}$$

The coefficient ρ relates to the decrease in profit assumed by the retailer and the corresponding increase in profit realized by the manufacturer. It is worth noting that the profit functions of the retailer and manufacturer meet the concave criteria for all included variables. Eqs. (39)-(45) provide the retailer and manufacturer mathematical treatise to seek optimal responses, and are presented as follows.

$$Q_R{}^* = \sqrt{2} . \sqrt{\frac{C_{O_R} . D}{2 . P_R . \rho + C_{h_R} . P_M}} \qquad \text{Eq. (39)}$$

$$P_R{}^* = \frac{\zeta . \left(\left(\theta . P_R{}^{-\alpha} . C_R{}^{\beta} . BL_{ratio_M}{}^{-\gamma} \times \left[\left[w_m + C_R\right] + C_{O_R} . Q_R{}^{-1}\right]\right) + \left(\frac{1}{2} . Q_R . C_{h_R} . P_M\right)\right)}{-\rho . Q_R + \left(\theta . P_R{}^{-\alpha} . C_R{}^{\beta} . BL_{ratio_M}{}^{-\gamma}\right)} \ if \zeta > 1 \qquad \text{Eq. (40)}$$

$$C_R{}^* = -\frac{\beta . C_{O_R} - P_R . Q_R . \beta + P_M . Q_R . \beta}{Q_R . (1+\beta)} \ IF\ \beta > 1 \qquad \text{Eq. (41)}$$

$$Q_M{}^* = \frac{\sqrt{2} . \sqrt{\frac{C_{h_m} . \left(\theta . P_R{}^{-\alpha} . C_R{}^{\beta} . BL_{ratio_M}{}^{-\gamma}\right) . \left(1-\frac{\left(\theta . P_R{}^{-\alpha} . C_R{}^{\beta} . BL_{ratio_M}{}^{-\gamma}\right)}{PC_M}\right) . \left(C_{B_M} + C_{h_M}\right) . \left(C_{S_M} + C_{O_M}\right)}{C_{B_m}}}}{C_{h_m} . \left(1-\frac{\left(\theta . P_R{}^{-\alpha} . C_R{}^{\beta} . BL_{ratio_M}{}^{-\gamma}\right)}{PC_M}\right)} \qquad \text{Eq. (42)}$$

$$B_M{}^* = \sqrt{2} . \sqrt{\frac{C_{h_M} . C_{B_M} . \left(\theta . P_R{}^{-\alpha} . C_R{}^{\beta} . BL_{ratio_M}{}^{-\gamma}\right) . \left(1-\frac{\left(\theta . P_R{}^{-\alpha} . C_R{}^{\beta} . BL_{ratio_M}{}^{-\gamma}\right)}{PC_M}\right) . \left(C_{B_M} + C_{h_M}\right) . \left(C_{S_M} + C_{O_M}\right)}{C_{B_M}{}^2 + C_{B_M} . C_{h_m}}} \qquad \text{Eq. (43)}$$

$$P_M{}^* = \frac{1}{C_R{}^{\beta}\theta}\left(\vartheta . BL_{ratio_M}{}^{\gamma} . P_R{}^{\alpha}\left(\frac{D\left(C_{S_M} + C_{O_M}\right)}{Q_M} - P_R . Q_R . \rho + \frac{1}{2} C_{h_M}\left(\frac{\left(-Q_M\left(1-\frac{(D)}{PC_M}\right) + B_M\right)^2}{Q_M\left(1-\frac{(D)}{PC_M}\right)}\right) + \frac{1}{2}\left(\frac{C_{B_M} . B_M{}^2}{\left(1-\frac{(D)}{PC_M}\right) . Q_M}\right) + \frac{C_R{}^{\beta}\theta\left(\eta_M BL_{ratio_M} + C_R + C_{P_M} + \left(u . D^{-\delta}\right)\right)}{BL_{ratio_M}{}^{\gamma} . P_R{}^{\alpha}}\right)\right) \ IF\ \vartheta > 1 \qquad \text{Eq. (44)}$$

$$BL_{ratio_M}{}^* = \frac{\varepsilon}{\eta_M} . \left(\frac{\gamma\left(u + C_R . D^{\delta} - P_M . D^{\delta} + C_{P_M} . D^{\delta}\right)}{D^{\delta}(1-\gamma)}\right) \ IF\ \varepsilon > 1 \qquad \text{Eq. (45)}$$

Note that in the Nash model, the best players' responses are $Q_R{}^*$, $P_R{}^*$, $C_R{}^*$, $Q_M{}^*$, $B_M{}^*$, $P_M{}^*$, $BL_{ratio_M}{}^*$, ρ^*, μ^* with the constraints described by Eqs. (27) to (32), and where Eqs. (36) and (46) are solved simultaneously by LINGO.

$$0 \le \rho^* \le 1 \qquad \text{Eq. (46)}$$

For retailers and manufacturers, the Stackelberg leadership conditions (47) and (48) are solved, respectively.

$$MAX\ \pi_R \qquad \text{Eq. (47)}$$

$$MAX\ \pi_M \qquad \text{Eq. (48)}$$

s.t	s.t
Eq. (42-45)	Eq. (39-41)
Eq. (27-32)	Eq. (27-32)
Eq. (36,46)	Eq. (36,46)
ρ^* , μ^*	ρ^* , μ^*

4.3. TPT Contract

In a TPT contract, the manufacturer, in addition to the wholesale price of (w_m), provides a fixed cost (t_m) that is independent of the retailer's order quantity. The profits gained by the manufacturer and retailer are given by Eqs. (49) and (50).

$$\pi_R = \left(\left(\theta.P_R{}^{-\alpha}.C_R{}^{\beta}.BL_{ratio_M}{}^{-\gamma} \times \left[[P_R - w_m - C_R] - C_{O_R}.Q_R{}^{-1}\right]\right) + (-\tfrac{1}{2} \times Q_R \times C_{h_R} \times P_M) - t_m\right) \quad \text{Eq. (49)}$$

$$\pi_m = \left([w_m - C_{P_M} - (u_M \times D^{-\delta_M}) - \eta_M BL_{ratio_M}] \times \theta.P_R{}^{-\alpha}.C_R{}^{\beta}.BL_{ratio_M}{}^{-\gamma}\right) - \left(\left(C_{h_M} \times \frac{\left(\left(1-\frac{\theta.P_R{}^{-\alpha}.C_R{}^{\beta}.BL_{ratio_M}{}^{-\gamma}}{PC_M}\right)\times Q_M - B_M\right)^2}{2\times\left(1-\frac{\theta.P_R{}^{-\alpha}.C_R{}^{\beta}.BL_{ratio_M}{}^{-\gamma}}{PC_M}\right)\times Q_M}\right) + \left(\frac{C_{B_M}\times B_M{}^2}{2.\left(1-\frac{\theta.P_R{}^{-\alpha}.C_R{}^{\beta}.BL_{ratio_M}{}^{-\gamma}}{PC_M}\right).Q_M}\right)\right) - \left([C_{S_M} + C_{O_M}].\frac{\theta.P_R{}^{-\alpha}.C_R{}^{\beta}.BL_{ratio_M}{}^{-\gamma}}{Q_M}\right) + t_m \quad \text{Eq. (50)}$$

The profit function of the retailer is concave to all variables. By obtaining the first derivation from the retailer and manufacturer functions and solving the equations so obtained, the best responses are presented as follows, including Eqs. (51) to (57).

$$Q_R{}^* = \sqrt{2} \times \sqrt{\frac{C_{O_R}\times C_R{}^{\beta}\times\theta}{BL_{ratio_M}{}^{\gamma}\times P_R{}^{\alpha}\times P_M\times C_{h_R}}} \quad \text{Eq. (51)}$$

$$P_R{}^* = -\frac{\alpha\times C_{O_R}+Q_R.C_R.\alpha+\alpha\times P_M\times Q_R}{Q_R\times(1-\alpha)} \quad \text{Eq. (52)}$$

$$C_R{}^* = -\frac{\beta.C_{O_R} - P_R\times Q_R.\beta + P_M\times Q_R.\beta}{Q_R.(1+\beta)}\ IF\ \beta > 1 \quad \text{Eq. (53)}$$

$$Q_M{}^* = \frac{\sqrt{2}.\sqrt{\frac{C_R{}^{\beta}.C_{h_M}.\theta.\left(1-\frac{\left(\theta.P_R{}^{-\alpha}.C_R{}^{\beta}.BL_{ratio_M}{}^{-\gamma}\right)}{PC_M}\right).(C_{B_M}+C_{h_M}).(C_{S_M}+C_{O_M})}{\eta_M BL_{ratio_M}{}^{\gamma}.P_{R_M}{}^{\alpha}.C_{B_M}}}}{C_{h_M}.\left(1-\frac{\left(\theta.P_R{}^{-\alpha}.C_R{}^{\beta}.BL_{ratio_M}{}^{-\gamma}\right)}{PC_M}\right)} \quad \text{Eq. (54)}$$

$$B_M{}^* = \frac{\sqrt{2}.\sqrt{\frac{C_{h_M}.\left(\theta.P_R{}^{-\alpha}.C_R{}^{\beta}.BL_{ratio_M}{}^{-\gamma}\right).\left(1-\frac{\theta.P_R{}^{-\alpha}.C_R{}^{\beta}.BL_{ratio_M}{}^{-\gamma}}{PC_M}\right).(C_{B_M}+C_{h_M}).(C_{S_M}+C_{O_M})}{C_{B_M}}}}{(C_{B_M}+C_{h_M})} \quad \text{Eq. (55)}$$

$$P_M^* = \vartheta.\left(\left[C_{P_M} + u_M \times D^{-\delta} + \eta_M BL_{ratio_M}\right] + \left(\left(C_{h_M} \times \frac{\left(\left(1-\frac{D}{PC_M}\right)\times Q_M - B_M\right)^2}{2\times\left(1-\frac{(D)}{PC_M}\right)\times Q_M \times D} \right) + \left(\frac{C_{B_M}\times {B_M}^2}{2\times\left(1-\frac{(D)}{PC_M}\right)\times Q_M \times D} \right) \right) + \left(\left[C_{S_M} + C_{O_M}\right] \times \frac{1}{Q_M} \right) \right) \; IF\ \vartheta > 1 \quad \text{Eq. (56)}$$

$$BL_{ratio_M}{}^* = \frac{\varepsilon}{\eta_M}.\left(-\frac{D.(-P_M + C_{P_M} + u_M \times D^{-\delta}) + \frac{D.\left[C_{S_M}+C_{O_M}\right]}{Q_{M_M}} + \left(C_{h_M} \times \frac{\left(-\left(1-\frac{D}{PC_M}\right)\times Q_M + B_M\right)^2}{2\times\left(1-\frac{(D)}{PC_M}\right)\times Q_M} \right) + \left(\frac{C_{B_M}\times {B_M}^2}{2\times\left(1-\frac{(D)}{PC_M}\right)\times Q_M} \right) - t_m}{D} \right) \; IF\ \varepsilon > 1 \quad \text{Eq. (57)}$$

In the Nash model, the best responses functions, including ${Q_R}^*$,${P_R}^*$,${C_R}^*$,${Q_M}^*$, ${B_M}^*$, ${P_M}^*$, ${BL_{ratio}}_M{}^*$, ${t_m}^*$ and μ^*, as well as the constraints described in Eqs. (27) to (32) and Eq. (58) are solved simultaneously to obtain the equilibrium.

$$0 \le {t_m}^* \le 1 \quad \text{Eq. (58)}$$

For retailers and manufacturers, the Stackelberg leadership conditions (59) and (60) should be solved, respectively.

$MAX\ \pi_R$ Eq. (59)

s.t

Eq. (54-57)

Eq. (27-32, 58)

${t_m}^*$, μ^*

$MAX\ \pi_M$ Eq. (60)

s.t

Eq. (51-53)

Eq. (27-32, 58)

${t_m}^*$, μ^*

4.4. Cost-sharing contract

A cost-sharing contract is used when the manufacturer and retailer both share the marketing costs, but which are paid by the retailer. This contract can play an important role in establishing coordination. The retailer and manufacturer models are represented in Eqs. (61) and (62), respectively.

$$\pi_R = \left(\left(\theta.{P_R}^{-\alpha}.{C_R}^{\beta}.{BL_{ratio_M}}^{-\gamma} \times \left[\left[P_R - w_m - (\omega).C_R\right] - C_{O_R}.{Q_R}^{-1} \right] \right) + \left(-\frac{1}{2}\times\ Q_R \times C_{h_R} \times P_M\right) \right) \quad \text{Eq. (61)}$$

$$\pi_M = \left(\left[P_M - C_{P_M} - \left(u_M \times D^{-\delta_M}\right) - \eta_M BL_{ratio_M} - (1-\omega)\times C_{R_m}\right] \times \theta.{P_R}^{-\alpha}.{C_R}^{\beta}.{BL_{ratio_M}}^{-\gamma} \right) - \left(\left(C_{h_M} \times \frac{\left(\left(1-\frac{\theta.{P_R}^{-\alpha}.{C_R}^{\beta}.{BL_{ratio_M}}^{-\gamma}}{PC_M}\right)\times Q_M - B_M\right)^2}{2\times\left(1-\frac{\theta.{P_R}^{-\alpha}.{C_R}^{\beta}.{BL_{ratio_M}}^{-\gamma}}{PC_M}\right)\times Q_M} \right) + \left(\frac{C_{B_M}\times {B_M}^2}{2\times\left(1-\frac{\theta.{P_R}^{-\alpha}.{C_R}^{\beta}.{BL_{ratio_M}}^{-\gamma}}{PC_M}\right)\times Q_M} \right) \right) - \left(\left[C_{S_M} + C_{O_M}\right] \times \frac{\theta.{P_R}^{-\alpha}.{C_R}^{\beta}.{BL_{ratio_M}}^{-\gamma}}{Q_M} \right) \quad \text{Eq. (62)}$$

The profit functions for both the retailer and manufacturer are concave for all variables. By obtaining the first derivative from the retailer and manufacturer functions and solving the equations so obtained, the best response function of each player for each decision variable can be illustrated as follows in Eqs. (63) to (69).

$$Q_R^* = \sqrt{2}.\sqrt{\frac{C_{O_R}.D}{C_{h_R}.P_M}} \quad \text{Eq. (63)}$$

$$P_R^* = \frac{\alpha.C_{O_R}+Q_R.C_R.\alpha.\omega+\alpha.P_m.Q_R}{Q_R\times(\alpha-1)} \quad \text{Eq. (64)}$$

$$C_R^* = -\frac{\beta.C_{O_R}-P_R.Q_R.\beta+P_M.Q_R.\beta}{Q_R.\omega(1+\beta)}\ IF\ \beta > 1 \quad \text{Eq. (65)}$$

$$Q_M^* = \frac{\sqrt{2}.\sqrt{\frac{C_{h_m}.\left(\theta.P_R{}^{-\alpha}.C_R{}^{\beta}.BL_{ratio_M}{}^{-\gamma}\right).\left(1-\frac{\left(\theta.P_R{}^{-\alpha}.C_R{}^{\beta}.BL_{ratio_M}{}^{-\gamma}\right)}{PC_M}\right).(C_{B_M}+C_{h_M}).(C_{S_M}+C_{O_M})}{C_{B_m}}}}{C_{h_m}.\left(1-\frac{\left(\theta.P_R{}^{-\alpha}.C_R{}^{\beta}.BL_{ratio_M}{}^{-\gamma}\right)}{PC_M}\right)} \quad \text{Eq. (66)}$$

$$B_M^* = \sqrt{2}.\sqrt{\frac{C_{h_M}.C_{B_M}.\left(\theta.P_R{}^{-\alpha}.C_R{}^{\beta}.BL_{ratio_M}{}^{-\gamma}\right).\left(1-\frac{\left(\theta.P_R{}^{-\alpha}.C_R{}^{\beta}.BL_{ratio_M}{}^{-\gamma}\right)}{PC_M}\right).(C_{B_M}+C_{h_M}).(C_{S_M}+C_{O_M})}{C_{B_M}{}^2+C_{B_M}.C_{h_m}}} \quad \text{Eq. (67)}$$

$$P_M^* = \frac{1}{C_R{}^{\beta}\theta}\left(\vartheta.BL_{ratio_M}{}^{\gamma}.P_R{}^{\alpha}\left(\frac{D(C_{S_M}+C_{O_M})}{Q_M} - P_R.Q_R.\rho + \frac{1}{2}C_{h_M}\left(\frac{\left(-Q_M\left(1-\frac{(D)}{PC_M}\right)+B_M\right)^2}{Q_M\left(1-\frac{(D)}{PC_M}\right)}\right) + \frac{1}{2}\left(\frac{C_{B_M}.B_M{}^2}{\left(1-\frac{(D)}{PC_M}\right).Q_M}\right) + \frac{C_R{}^{\beta}\theta\left(\eta_M BL_{ratio_M}+C_R+C_{P_M}+(u.D^{-\delta})\right)}{BL_{ratio_M}{}^{\gamma}.P_R{}^{\alpha}}\right)\right)\ IF\ \vartheta > 1 \quad \text{Eq. (68)}$$

$$BL_{ratio_M}{}^* = \frac{\varepsilon}{\eta_M}.\left(\frac{\gamma(u+C_R.D^{\delta}-P_M.D^{\delta}+C_{P_M}.D^{\delta}-C_R.D^{\delta}.\omega)}{D^{\delta}(1-\gamma)}\right)\ IF\ \varepsilon > 1 \quad \text{Eq. (69)}$$

In the Nash model, best response equations include $Q_R{}^*$, $P_R{}^*$, $C_R{}^*$, $Q_M{}^*$, $B_M{}^*$, $P_M{}^*$, $BL_{ratio_M}{}^*$, μ^* and ω^* with regard to the constraints described, and Eqs. (26) to (31) and (70) should be solved simultaneously.

$$0 \le \omega^* \le 1 \quad \text{Eq. (70)}$$

For retailers and manufacturers, the Stackelberg leadership conditions (71) and (72) should be considered, respectively.

$MAX\ \pi_R$ Eq. (71)

s.t

Eq. (66-69)

Eq. (27-32, 70)

μ^* , ω^*

$MAX\ \pi_M$ Eq. (72)

s.t

Eq. (63-65)

Eq. (27-32, 70)

μ^* , ω^*

5. Testing the Model

The authors benchmarked the performance of the four coordination models under bot the Nash and Stackelberg game-playing situations in a considered two-echelon SC. The numerical data (initial conditions) for the various relevant parameters are presented in Table 6.

Table 6. Initial conditions used the model (Source: Authors)

θ	α	β	γ	u_M	δ_M	PC_M	C_{P_M}	Z
3	*2.25*	*1.05*	*1.61*	*4*	*0.01*	*15*	*10*	*1.1*
C_{h_M}	C_{B_M}	C_{O_M}	C_{S_M}	C_{O_R}	ε	ϑ	C_{h_R}	
0.5	*1*	*4*	*7*	*5*	*1.1*	*1.1*	*0.15*	

The Nash and Stackelberg models are optimized using a global solver in LINGO. The sensitivity of the forced labour ratio for the four contracts in the Nash mode have been analysed. As illustrated in Fig. 7, the revenue and profit-sharing contracts are not apparently affected by changes in the forced labour ratio. Moreover, Figs. 7(b) and 7(d) indicate the inverse relationship between profit and the proportion of forced labour for cost-sharing and two-part tariff contracts, respectively. Note that the x-axis represents the BL_{ratio} and the y-axis the profit from SC based upon each contract, in USD.

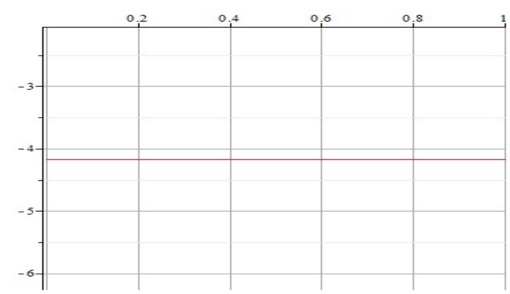


Figure 7(a). revenue-sharing contract

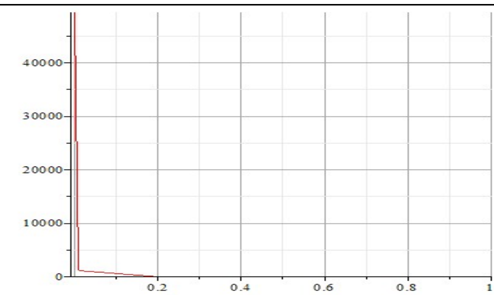


Figure 7(b). cost-sharing contract

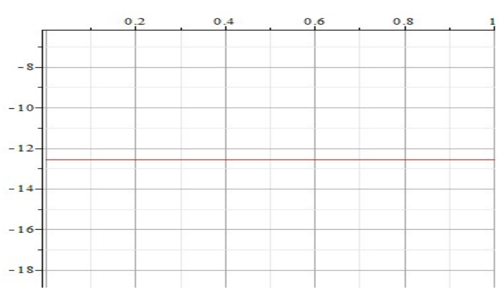


Figure 7(c). profit-sharing contract

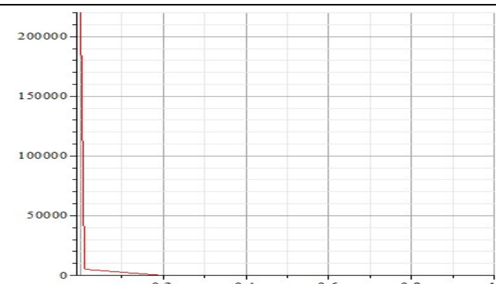


Figure 7(d). TPT contract

Moreover, as presented in Fig. 8, when comparing contracts in the Nash model the TPT and cost-sharing contracts show greater profitability. The degree of sensitivity of the two-part tariff is much greater. Note that the x-axis represents the BL_{ratio} and the y-axis the changes in profit from SC based upon each contract, in per cent.

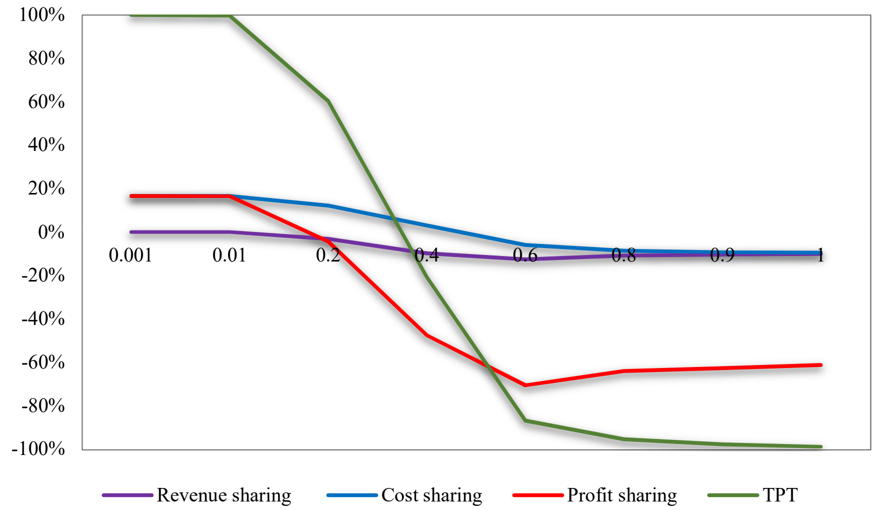
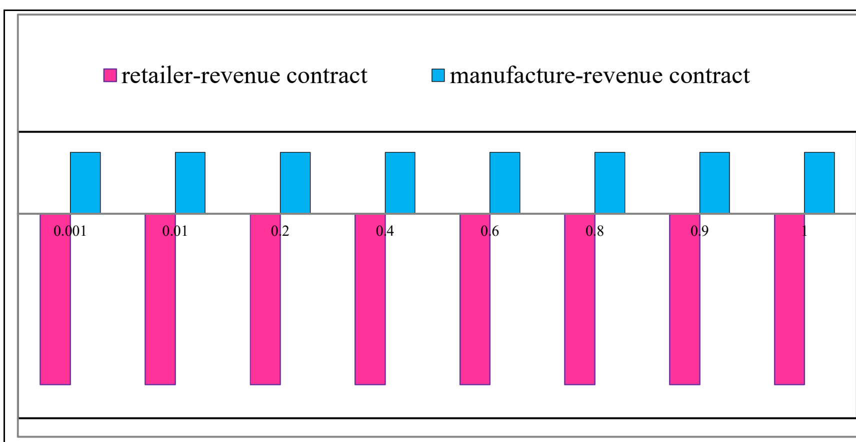


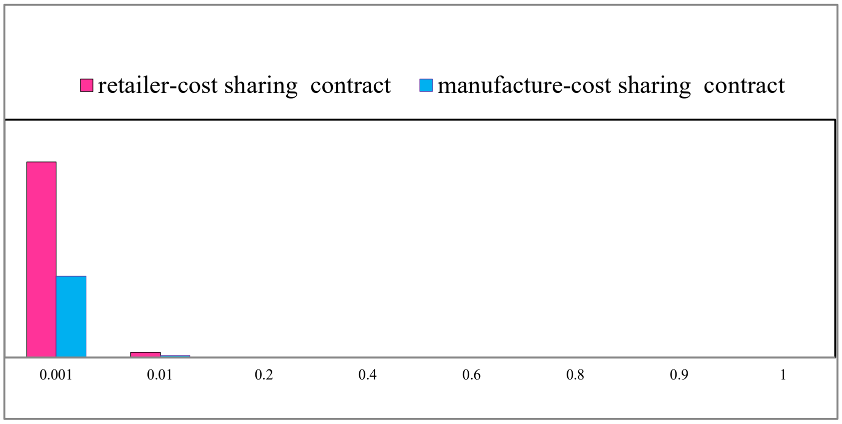
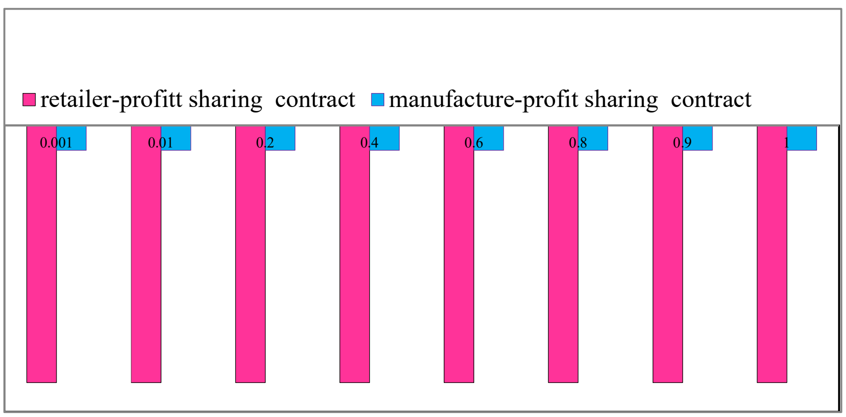
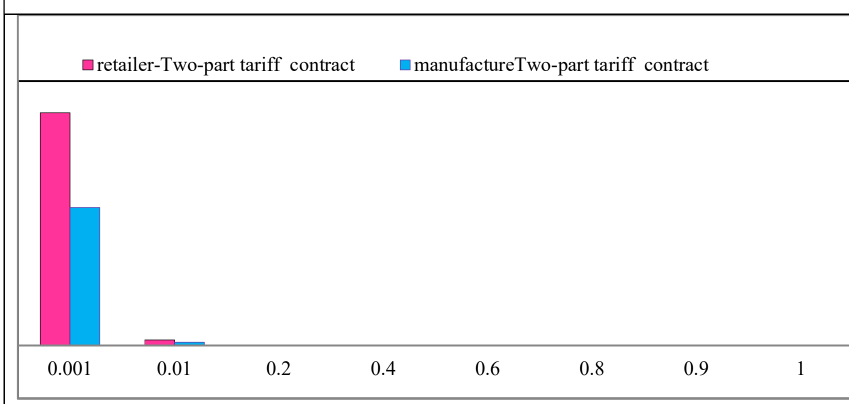
Figure 8. Nash Model results for all contracts

Secondly, the sensitivity of negative CSR due to forced labour is investigated considering the retailer Stackelberg leadership game. The results indicated that SC profit is not particularly sensitive to changes in forced labour. Moreover, TPT and cost-sharing contracts showed greater profits. Ultimately, the sensitivity analysis of the forced labour ratio for manufacturer leadership games was investigated. As analysed, the sensitivity of the profit and social responsibility was strictly observed in profit-sharing contracts; however, in other cases, this sensitivity was found to be close to zero. For manufacturer leadership, the results of comparing coordination contracts show the same results.

Profitability changes for each player in the Nash and Stackelberg games are depicted in relation to changes in forced labour ratio. The interpretations of each image have been briefly summarized in Table 7. Note that the x-axis represents the BL_{ratio} and the y-axis the profit of the retailer and manufacturer (in two different colours) based on each contract, in USD.

Table 7. Nash mode comparing retailer and manufacturer profits separately for each contract type

	In the revenue-sharing contract, the profitability of the retailer is always greater than that of the manufacturer because of the fact that the manufacturer has assumed the costs of reducing the

	ratio of the forced labour, which leads to loss (unless this ratio reaches zero).
	In the cost-sharing contract, the profitability of the retailer is always greater than that of the manufacturer. However, if both players benefit from greater profitability, the forced labour ratio approaches zero. Note that the maximum BL_{ratio} is 1% worldwide
	In the profit-sharing contract, with regard to the forced labour ratio, both parties suffer losses, though these losses are much higher for the manufacturer than the retailer
	The two-part tariff contract is the same as the cost-sharing contract.

To avoid repetition, in the Stackelberg mode by comparing retailer and manufacturer profits, the results indicated that:

[1]. In the revenue-sharing contract, profitability is very high for the retailer. Therefore, social responsibility costs in the Stackelberg model are recommended for consideration by the retailer;

[2]. With a zero forced labour ratio, the retailer obtains the highest profit. Accordingly, in the cost-sharing contract, this ratio is recommended more for the retailer's Stackelberg mode;

[3]. In the profit-sharing contract, the recommendations are the same as for cost-sharing. However, profitability is minimal; thus, social responsibility is better not to be considered;

[4]. In the TPT contract, in order to prevent the loss of players, social responsibility has to be taken seriously, otherwise, especially in the manufacturer leadership mode, considerable losses will result.

6. Discussion and Implications

Generally, corporate social responsibility is one of the most important and distinct dimensions in supply chain management. Very little research has been performed in the area of social responsibility, with the majority of research focussing on the economic and environmental fields. Furthermore, the social responsibility requirement is of particular importance to consumers and company shareholders. Thus, in this research, the quantitative and measurable social responsibility index called the forced labour ratio in the SC has been examined. The decisions made by the members of a supply chain play a direct role in determining the profits of each member. These decisions are occasionally in conflict with other members in a competitive environment. In this paper, contradictory variables, including the costs arising from observing corporate social responsibility, inventory and stock-outs, advertising costs and pricing in a two-echelon SC that includes a manufacturer and a retailer, have been considered. Because CSR requirements are often imposed on manufacturers by shareholders, governments, and customers, the cost of social responsibility is generally assumed by the manufacturer, whilst the retailer is responsible for advertising the final product due to their direct relationship with the customer. The manufacturer and the retailer outcomes were modelled, and the best responses were obtained for each player. Afterward, Nash and Stackelberg conditions, assuming leadership by either the retailer and the manufacturer for four different coordination contracts (revenue sharing, profit sharing, cost sharing, and TPT) were modelled. Eventually, by nonlinear optimization, the sensitivity analysis of the social responsibility index (BL_{ratio}) was investigated. According to the results presented above, in the Nash model, revenue and profit-sharing contracts were rarely sensitive to BL_{ratio} changes; in the Stackelberg mode of the retailer's leadership, revenue sharing, and profit-sharing and TPT contracts were rarely sensitive; and in the Stackelberg model of the manufacturer leadership, the same was true of revenue sharing, cost-sharing and TPT contracts.

Theoretically speaking, since 2009, except for a notable few research efforts (Panda, 2014; Hesueh, 2014; Hong & Guo, 2019; Mahdiraji et al., 2019) the CSR concept has not been quantitatively analysed in any broad sense. However, in this research, CSR, and its effects on SC profitability, have been considered in detail. In this regard, one concept or sub-criterion of the CSR, that of forced labour, has been selected as the most deterministic factor (Mahdiraji et al., 2019). The effects of the chosen criteria on the profitability of SC and its members was analysed through four coordination contracts in a given two-echelon supply chain. Furthermore, CSR was considered and analysed quantitatively, and the benchmarking for four coordination contracts was illustrated. As a result, contracts including profit and revenue sharing were found not to be sensitive to CSR changes; however, the TPT and cost-sharing contracts were extremely sensitive to changes in CSR.

For application implications, note that in real-world cases, considering the 3.4 billion members of the worldwide workforce, nearly 25 million can be considered to be in forced labour, or 0.7%. This rate for Asia and the Pacific, as the sector with the greatest proportion of forced labour, is nearly 1%. Thus, the results for the higher amount of BL_{ratio} have fortunately not yet occurred in a real-world scenario. The results in Fig. 7 and Table 7 illustrate that for a BL_{ratio} greater than 20%, the players and supply chain in any contract type will incur losses. By comparing the manufacturer's and retailer's profit in the Nash and Stackelberg modes, as based upon coordination contracts, one find the following results. In the Nash game, revenue sharing contracts result in higher profitability for the retailer than the manufacturer. Thus, the manufacturer has incurred costs by being obliged to reduce the forced labour ratio, leading to losses unless the ratio can be brought to zero. Moreover, in a revenue sharing contract with Stackelberg conditions, profitability will be very high for the retailer. Therefore, it is recommended that the retailer also consider observing the appropriate social responsibility. Further, under Nash equilibrium conditions, for the cost-sharing contract, the profitability of the retailer is always greater than that of the manufacturer. Table 8 compares the suitability of each contract for each player and the supply chain.

Table 8. Comparison of all considered scenarios

Game Type	Contract Type	Results for Retailer	Results for Manufacturer	Results for Supply chain
Nash bargaining game; (static)	Revenue Sharing	☒	☑	☒
	Cost Sharing	☑	☑	☑
	Profit-Sharing	☒	☒	☒
	TPT	☑	☑	☑
Stackelberg leader-follower game (Dynamic)	Revenue Sharing	☑	☑	☑
	Cost Sharing	☑	☑	☑
	Profit-Sharing	☑	☑	☑
	TPT	☒	☒	☒

Game Type	Contract Type	Results for Retailer	Results for Manufacturer	Results for Supply chain
		Loss (☒)	Profit (☑)	

Contrary to previous modes in the Nash game and profit-sharing contract, both sides will suffer losses, which will be much higher for the manufacturer. In the Stackelberg-profit sharing contract, profitability is minimal even if social responsibility is not observed. The interpretation of the Nash-TPT contract is similar to that of the Nash-cost sharing contract. In the Stackelberg-TPT, social responsibility requires a degree of control to prevent losses being incurred by the players; otherwise, huge loss will be incurred.

Moreover, to use the designed approach in real-world cases and situations, a few points should be considered. First, should the power of the retailer and manufacturer be equal (static game and Nash equilibrium), cost-sharing and TPT contracts are more productive for the chain. However, in leader-follower situations with a dominant player, whether this be the manufacturer or retailer, all contract types except TPT are profitable. Moreover, for Stackelberg game conditions, cost sharing is ranked first, and revenue sharing and profit sharing are ranked second and third, respectively. It is obvious that due to the negative indicator used for CSR in this research, agreements based on cost have higher priority than profit-based contracts. For a real-world situation, the structure below is proposed.

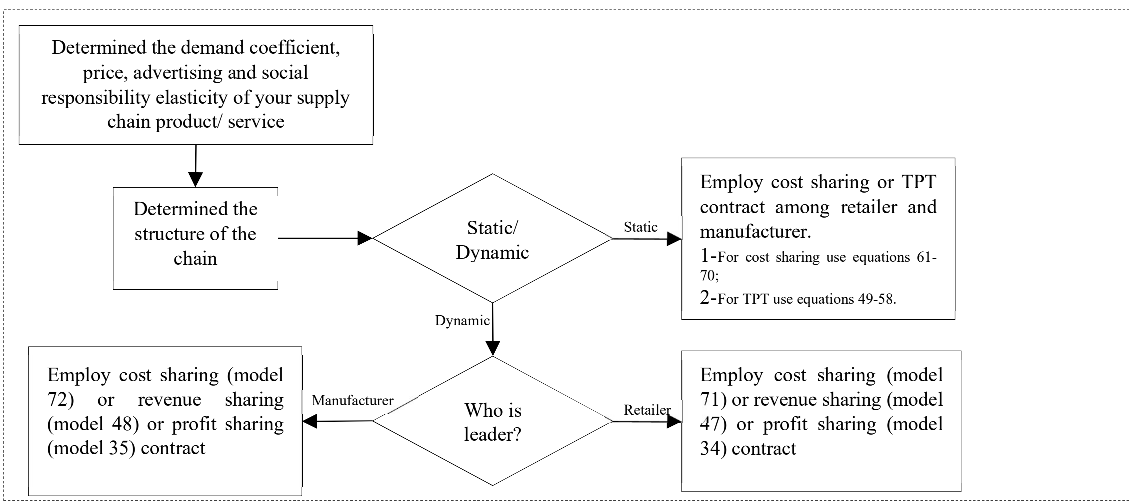


Figure 9. Proposed structure

After employing the proposed scheme, the designed model should be coded and solved by a relevant software (e.g. MATLAB). The results could determine the quantity, price, CSR indicator, etc. for each member of the supply chain.

7. Conclusion

This paper develops a non-linear mathematical model to determine the direct impact of 'forced labour' on supply chain profitability according to different contract types and static and dynamic games. Also, this is the first time that CSR has been considered in coordination contracts as a determining factor, and has been analysed accordingly. Also, the paper illustrates how game playing behaviour between the supply chain members can be modelled using the 'Nash' and 'Stackelberg' models. For practitioners, this paper provides guidelines to evaluate the impact of the negative CSR parameter, 'forced labour', on their profitability and, ultimately, the 'bust' scenario for their business. Moreover, business owners/managers should be able to determine the relative value of different coordination contracts and their implications for the supply chain for 'Nash' or 'leader-follower' relationships.

Note that in this paper, the researchers have adopted a negative specific CSR indicator from the related literature; thus, investigating positive metrics such as income derived from social responsibility, the concept of consumer super-welfare could be considered in future studies. For the same reason, the review of coordination contracts as one of the mechanisms of collaboration with potential demand and social responsibility should be considered. Moreover, in this research, the authors considered the market and demand to be predictable, and hence applied a nonlinear deterministic demand function; nonetheless, an uncertain demand function is likely to be much more realistic in a real-world scenario. Accordingly, the authors propose the adoption of probabilistic (e.g., normal or uniform distribution functions) or stochastic demand functions or parameters for further investigation. It is worth noting here that coordination contracts' structure and formulation should be redesigned for uncertain situations, as either stochastic or probabilistic. Besides, in this research, based on the literature review and studied papers (see Table 1), four coordination contracts were selected. Nevertheless, in future research, advanced purchasing discounts, quantity flexibility, options contracts, risk-sharing contracts, etc., might well be considered. These contracts have mainly been examined in uncertain demand modelling circumstances without considering CSR indicators. In addition, from a game theory perspective, Nash and Stackelberg equilibria and games were studied by the authors in this research. The aforementioned games are static and dynamic, respectively, with complete information. However, in real-world cases, incomplete and imperfect situations are highly like to exist or arise; thus, employing relevant games such as signalling games and pertinent equilibriums such as the Nash Perfect Equilibrium (NPE) could yield interesting results.

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Appendix 1.

Table 1. Related researches in the area of profit-sharing, revenue sharing, cost-sharing, and two-part tariff contracts

Scholar, Year	SC Echelon	Type of Contract; Buyback (BB); Revenue Sharing (RS); Discounts (D); Cost Sharing (CS); Profit Sharing (PS); Rebate (R); Information Sharing (IS); Option (OC)	Demand Function; Stochastic (S)/ Deterministic (D)	Linear (L) /nonlinear (N) demand function	Demand variables; Price (P); Green & Sustainable (G); Social Responsibility (R); Quality (L); Advertisement & Marketing (A); Quantity (Q)	Main variable; price (P); Order Quantity (Q); Contract Variable (C); Advertisement & Marketing (A); Green & Sustainable (G)
Krishnan & Winter, 2011	2	RS	S	L	Q	P/C
Zhao & Shi, 2011	2	RS/D	S	L	Q	P
Kaya, 2011	2	D/TPT/CS	S	L	R	C
He & Khouja, 2011	2	RS/BB/PS	S	L	Q	C
Toktas-Palut & Ülengin, 2011	2	CS	S	L	Q	P/Q
Zhang et al, 2012	2	RS	D	L	P	P/Q
Govindan et al, 2012	2	RS/BB/D	S	L	Q	P/Q
Saha, 2013	2	RS/R/CS	D	L/N	P/R	P/Q/G
Palsule-Desai, 2013	2	RS	D	L	P	P/C
Ma et al, 2013	2	TPT	D	L	P/A/L	P/Q/C
Panda, 2014	2	RS	D	L	P	C/P/Q/A
Chen & Su, 2014	2	RS	S	L	P	P/Q
Govindan & Popiuc, 2014	3	RS	S	L	Q	P/C
Feng et al, 2014	2	RS	S	L	Q	C
Hsueh, 2014	2	RS	S	L	R	P/Q/C
Lei et al, 2015	2	IS/RS	S	L	Q	Q
Seifbarghy et al, 2015	2	RS	D	N	P/L	P/Q
Avinadav et al, 2015	2	RS/D	D	L	P/L	P
Alaei & Setak, 2015	2	RS	S	L	Q	P/Q
Cao et al, 2015	2	PS	S	L	P	P
Ghosh & Shah, 2015	2	CS	D	L	P/G	P/Q/G
Saha & Goyal, 2015	2	CS/D	D	L	P	P/Q
Sluis & Giovanni, 2016	2	RS/BB/D/R	D	L	Q	C
Modak et al, 2016	3	RS/D	D	N	P	P/C
Weraikat et al, 2016	2	RS	S	L	Q	P/Q
Hu et al, 2016	3	RS	S	L	Q	P
Becker-Peth & Thonemann, 2016	2	RS	S	L	Q	Q
Xu et al, 2016	2	RS/TPT	D	L	P/G	P/G
Zhou et al, 2016	2	CS	D	L	A/G	P/G
Zhang & Ren, 2016	3	CS/RS	S	L	Q	P

Scholar, Year	SC Echelon	Type of Contract; Buyback (BB); Revenue Sharing (RS); Discounts (D); Cost Sharing (CS); Profit Sharing (PS); Rebate (R); Information Sharing (IS); Option (OC)	Demand Function; Stochastic (S)/ Deterministic (D)	Linear (L) /nonlinear (N) demand function	Demand variables; Price (P); Green & Sustainable (G); Social Responsibility (R); Quality (L); Advertisement & Marketing (A); Quantity (Q)	Main variable; price (P); Order Quantity (Q); Contract Variable (C); Advertisement & Marketing (A); Green & Sustainable (G)
Yang et al, 2016	2	PS/RS	S	L	Q	Q
Pfeiffer, 2016	2	TPT/D/RS	D	L	P	P/C
Wang et al, 2016	2	D/CS	S	L	P/G	P/Q
Xie & Liang, 2017	2	RS	D	L	A	P/C
Hu & Feng, 2017	2	RS	S	L	Q	Q/C
Peng et al, 2018	2	RS	D	L	P/G	P/G/Q
Chakraborty et al, 2018	2	RS/CS	D	N	A/P	A/P/
Sher et al, 2018	2	CS	D	L	P	P/Q
Hu et al, 2018	2	OC	S	L	P	P
Hu et al, 2018	2	PS	S	L	P	P/Q
Hong & Guo, 2019	2	CS/TPT	S	L	P/G	P/G/A
Li et al, 2019	2	TPT	S/D	L	P	P
Mahdiraji et al, 2019	2	RS/BB/R	S	N	Q	Q/P
Mahdiraji et al, 2019	2	RS	D	N	P/A/R	Q/P/A
Fan et al, 2019	2	PS	S	N	P	P/Q
Adhikari et al, 2020	2	RS	S	N	P	P/Q
Zhang et al, 2020	2	RS	D	L	P	P/Q
Proposed Research	2	RS/CS/TPT/PS	D	N	P/A/R	Q/C/P/A